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# CAN bus technology for agricultural machine management research and undergraduate education

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**CAN bus technology for agricultural machine management research and undergraduate education**

by

**Firas Salim Al-Aani**

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

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## NOMENCLATURE

| | |
|---|---|
| 2WD | Two-wheel drive |
| 4WD | Four-wheel drive |
| ABE | Agricultural and Biosystems Engineering |
| ACK | Acknowledgment |
| ASABE | American Society of Agricultural and Biological Engineers |
| ASAE | American Society of Agricultural Engineers |
| ASCII | American Standard Code for Information Interchange |
| ATV | All-Terrain Vehicle |
| BCRF | Bio Century Research Farm |
| Bus | Binary Unit System |
| CAN | Controller Area Network |
| CAN-H | CAN High |
| CAN-L | CAN Low |
| CAPL | Communication Application Programming Language |
| CRC | Cyclic Redundancy Code |
| CSV | Comma Separated Value |
| DA | Destination Address |
| DAQ | Data Acquisition Systems |
| DB | Data Base |
| DLC | Data Length Code |
| ECU | Electrical Control Units |

| | |
|---|---|
| Ef | Field Efficiency |
| EFC | Effective Field Capacity |
| EOF | End Of Frame |
| FMIS | Farm Management Information System |
| GDP | Gross Domestic Product |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| IDE | Identifier Extension |
| IMU | Inertial Measurement Unit |
| ISO | International Standard Organization |
| ISU | Iowa State University |
| JD | John Deere |
| KPI | Key Performance Indicators |
| LSB | Least Significant Bit |
| LVDS | Low Voltage Differential Signaling |
| Matlab | Matrix Laboratory |
| MCU | Microcontrollers |
| MDI | Medium Dependent Interface |
| MSB | Most Significant Bit |
| NI | National Instruments |
| OEM | Original Equipment Manufacturer |
| PDU | Protocol Data Unit |
| PGN | Parameter Group Number |

| | |
|---|---|
| PLS | Physical Signaling |
| PMA | Physical Medium Attachment |
| PSI | Pounds Per Square Inch |
| PTO | Power Take Off |
| RTK | Real Time Kinematic |
| RTR | Remote Transmission Request |
| SAE | Society of Automotive Engineering |
| SAS | Statistical Analysis System |
| SEO | Search Engine Optimization |
| SOF | Start Of Field |
| SQL | Structured Query Language |
| TFC | Theoretical Field Capacity |
| TPMO | Tractor Performance Monitoring and Optimization |
| USB | Universal Serial Bus |

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*Firas Salim*

## ABSTRACT

To evaluate each agricultural operation, we need data to measure and monitor the mechanization unit performance. Many systems have been developed to determine tractor performance monitoring and optimization (TPMO), but the majority of these systems were not fully adequate. In 1986, the Mercedes Corporation collaborated with Robert Bosch and developed Controller Area Network (CAN) Bus technology. This technology is a communication system in vehicles and allows connections between multiple Electrical Control Units (ECUs). Currently, the improvement in electronic technology has made field operational management easier to monitor. This new CAN Bus technique is becoming widely used application in agriculture to help farmers determine and improve field efficiency, while decreasing equipment costs using the data obtained from tractors.

Prior to CAN Bus, ECUs were developed to make communication between systems easier, faster, and more efficient without using point to point connection. Modern tractors are supplied with monitors to show engine rpm, forward speed, and slip percentage. CAN messages depend on the broadcast system and can be controlled and filtered through dedicated software such as Vector Canoe and CAN Analyzer. These messages are continuously updating information about the engine, power train, equipment, power take off, hydraulic system, and others. The emergence of the new technology of extensive field monitoring and data collection programs has caused many operational practices to be abandoned. For example, in the last century, the need for measuring fuel consumption at each speed, gear shift and to the whole operation has been reduced with the application of the telemetry systems. Also, we can reduce the amount of labor, tools, operational costs and time required.

A major purpose for evaluating agricultural machinery is to obtain accurate information and assessment about different agricultural practices. This information provides the operators with feedback that can assist the operator in acquiring and improving the field data, managing limited resources, and acting accordingly. Such data logging systems will help the users of agricultural machinery have a good understanding of performance activities by gathering and saving the data efficiently and make a significant progress in improving performance parameters.

# CHAPTER 1. GENERAL INTRODUCTION

## 1.1 Background

Thousands of years ago, people planted their food manually, and today there are some areas in developing countries where people are still using manual cultivation methods, especially when they have small farms and labor is inexpensive. The first agricultural machines and tools were made from woods and bones, but since they have been developed to include such materials as iron, stainless steel, and copper. Although agricultural operations are very useful to produce more outputs with less input, they consume money, time, and energy. Agricultural practices are still stressful in most regions especially when they perform with simple tools. The application of techniques like mechanization and precision agricultural equipment has led to an emergence of positive results such as reducing time and costs, and increasing productivity; therefore this type of equipment is indispensable in agricultural production.

Assessing the performance of any agricultural operation within the field is done by relying on a combination of factors such as fuel consumption, productivity, slippage percentage, and capacities. However, using agricultural machinery in large areas without managing such factors as time, fuel consumption, and slippage percentage will increase the negative consequences and affects the optimization of agricultural production (Grisso et al., 2008).

## 1.2 Problem Context

This study focuses on two major problems in agricultural mechanization. The first one is low productivity in some countries in mechanized farming which includes efficiency, and the second is the increasing costs of operations, which includes fuel consumption. These countries also suffer from the lack of resources and the lack of electronic data in agricultural machinery to improve productivity and reduce costs. This dissertation presents three experiments which evaluate performance of agricultural machinery by using the electronic data. Thus, to rectify the above problems, governments, machinery owners and other stakeholders need to increase the operational efficiency and accuracy in order to reduce shortfalls in the food production system. This is an essential element to improving the regulations and use of agricultural machines and implements that suffer from poor management resulting in suboptimal production (Taylor et al., 2002).

## 1.3 Objectives

The overall objectives of the study was to improve the agricultural operations, food security, and techniques which can be achieved through the following set of goals:

1- Developing methods and protocols to directly quantify the power requirements of agricultural machines utilizing electronic vehicle networks.

2- Estimating machines’ capacity and utilization based on automatic data analysis from agricultural machinery.

3- Develop teaching modules to train future leaders in the use of CAN bus to meet agricultural efficiency goals.

## 1.4 Introduction

Agricultural machinery plays an important role in improving performance, agricultural productivity, and reducing costs. They also play an essential part of raising the level of performance of labor in the agricultural fields through horizontal and vertical expansion. Therefore, governments and stakeholders should plan to increase the productivity of planted area to meet the required need of food for citizens. This requires studying how to use automation to improve the productivity of machines that are already in use to compensate for the shortage in developing countries (Wang, 2001). Tillage has been defined from ASABE standards as “the changing of soil condition for the enhancement of crop production” (ASABE, 2005).

With regard to power consumption, tillage is the most important operation in agriculture, consuming at least half of the engine power and 30 percent of the total power consumption in the USA agriculture. Tilling the soil produces ideal soil conditions by improving the relationship between air and water and soil for crop growth. Thus, growers that use tillage operation are concerned about tillage, and they are seeking ways to reach optimum production by substituting human power with mechanical power (Ahaneku et al., 2011).

Conservation tillage started in the 1980s, but the basic concepts and the purpose of tillage are still the same today. Although many methods have been developed for measuring the performance of different agricultural machinery, there is still a lack of consensus of which method is the best. For example, there is a lack of consensus on choosing the right implement, speed, and depth. Farmers often follow the operations that they learn from parents and neighbors and it’s very difficult to change. Sometimes these improper practices lead to economic losses and soil failure.

Tillage can be separated into primary tillage and secondary tillage. Primary tillage is "that which constitutes the initial major soil working operation. It is normally designed to reduce soil strength, cover plant materials, and rearrange aggregates" (ASABE, 2005). Secondary tillage implements till the soil to a shallower depth than primary tillage implements, provide additional pulverization, and mix pesticide and fertilizers into the soil. Secondary tillage operations also level and firm the seedbed in preparation for planting. A field cultivator is a secondary tillage implement used for seedbed preparation, weed eradication, or fallow cultivation subsequent to some form of primary tillage (ASABE, 2009). Since power requirements depend on tool design, soil type, and condition, optimizing agricultural machinery has a major impact on the performance.

Tractors and agricultural machinery have been designed as a standard for land preparation, tillage, and other agricultural operational tasks. Tractors are the primary source to provide power in farms and fields (Birrell, 2017). Thus, to obtain the optimum output from tractors, management and optimal utilization should be applied. Tractor performance has been studied over the past three decades and optimum results could be obtained for different agricultural machinery (Stombaugh et al., 2008). It is always desirable to have the most power converted from the engine to traction power which results in lower energy loss during the agricultural operation (Ahaneku et al., 2011). It has been found that 12-18% of the engine power is consumed before starting the operation (Sabanci, 1997). Another 20-40 % of power is lost between the axles and the ground (Mowitz et al., 1987). Improper selection of tractor size can cause excessive operating costs. Therefore, matching tractors with implements would lead to improving the performance of operation.

For each soil condition, and tire design, there are some variables and parameters that affect the tractor performance such as implement size, practical speed, and depth of operation. These variables can be easily managed and controlled by the operators to optimize the delivery of power to the field. In addition, tire inflation pressure and ballasting weight are essential for evaluating and managing the performance. To obtain the best performance with least cost, ballasting and correct tire inflation must be maintained (Sümer et al., 2005). Improper adjustments leads to fuel waste, tire wear, and drive train damage, and these effects decrease productivity and efficiency (Stombaugh et al., 2008). Wulfsohn et al. (2009) found that ballasting and tire inflation pressure played a significant role in tractor fuel consumption and tractive performance. A 4% to 7% improvement in tractive efficiency was obtained while using correct ballast and lowering tire inflation pressure to optimal as compared to overinflated tires (Zoz et al., 1994). Lancas et al. (1997) reported that 18% to 20% of fuel was saved when they used low-correct inflation pressure with regard to axle load. Moreover, they found 4.6% to 7.5 % in productivity was gained.

Proper ballasting weight parameters means using a certain amount of weight on each axle of a tractor to deliver more engine power to the tractor drawbar which will decrease fuel consumption and wheel slippage (Hanna et al., 2010). Tractor weight and the distribution of this weight between front and rear axles both are very important to determine the proper tractor ballasting needed (Stombaugh et al., 2008). Additionally, tractor efficiency can be increased when working on a hard land soil and by increasing the load on the drive wheels of the tractor. Specifically, the increased load on the driving wheels helps to increase the traction between the wheels and the ground, and to reduce slip ratio, which increases the speed of the tractor and thus increase efficiency and productivity. However, in soft soil, adding weight on the driving wheel will help to reduce the slippage percentage and improve the drawbar power (Dwyer, 1985).

Similarly to proper ballasting weight, correct tire inflation pressure parameters are the second key for improving the tractive performance of agricultural tractors. Adjusting tire inflation pressure is an important consideration in controlling tractor performance optimization in two ways. The first is by affecting the tire contact area with the soil causing an effect in tire traction. Second, slippage percentage increases loss of the energy provided by the engine (Battiato et al., 2013). Recent studies and researches have been conducted and found that decreasing inflation pressure increases tractors tractive performance. In spite of this, many operators make the common mistake of leaving the tires overinflated (Stombaugh et al., 2008).

To obtain good advantages from these aspects, tractors should be evaluated and examined based on overall productivity, fuel consumption, and travel reduction for various agricultural operations. These are good indicators for the performance of agricultural machine for particular agrotechnical operation and are considerable crucial to farmers and in the priorities of agricultural machinery designers. Simultaneously, the primary techniques for estimating, evaluating, measuring and analyzing agricultural operations such as tillage, planting, and harvesting are still slow, cost money, and more labors. To a great extent, instrumentation systems for testing machines need calibrations and verifications and that makes the process more complex.

Some studies have been made to improve the guidance system and the evaluation of machinery performance parameters. Light-bar systems and auto guide technology are used to allow farmers in guiding the rovers. Another technique has used spatial data collection for agricultural data collection. The Global Positioning System (GPS) has been used from farmers to monitoring field operations and aid the agricultural producers to apply complex tasks and make it affordable.

### 1.5 Thesis Format

This thesis incorporates work done to progress towards the overall project goal, separated into three primary technical chapters. This thesis begins with a general introduction and background general introduction of the topic, and continues with a literature review. The general introduction and background demonstrate the importance of the research conducted within this thesis. Following the literature review, the objectives for this thesis are described. The thesis will then begin with the first of three technical chapters.

The first technical chapter (Chapter 3), entitled "Design and validation of an electronic data logging systems (CAN Bus) for monitoring machinery performance and management-Tillage application" was presented at 2016 ASABE Conference and will be submitted as a research article to the journal Applied Engineering in Agriculture. This article explores the informational introduction to the widespread use of controller area network (CAN) bus technology, as well as a summary about interpreting the massive amount of real-time machine data. Raw operational data and machine analytics in agriculture.

The second technical chapter (chapter 4), entitled "Design and validation of an electronic data logging systems (CAN Bus) for monitoring machinery management- Planting application" was presented at 2018 ASABE as a conference paper and will be submitted as a research article to the journal Applied Engineering in Agriculture. This article examines the adoption of controller area network in tillage application. CAN systems enable real-time streaming data to extract key performance indicators (KPI).

The third technical chapter (chapter 5), entitled "Design and validation of course improvement and student learning performance for Controller Area Network". This article focuses on developing teaching modules to train future leaders in the use of CAN Bus to meet agricultural efficiency goals.

The end goal for these experiments are to help the future of electronics processing facilities the monitoring of agricultural machinery so they can be optimized and utilized properly. Thus, the research conducted for this dissertation was performed to provide helpful guidance to owners, users, and researchers.

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# CHAPTER 2. BACKGROUND ON CONTROLLER AREA NETWORKS

## 2.1 Background

Agricultural machinery is an essential part of creating viable solutions to the grand challenges facing human food security. Agricultural mechanization techniques have exponentially increased and improved over the past couple of decades, and these techniques increased efficiency, productivity, and machine durability. The current evolution and adaptation of these technologies through their integration of agricultural equipment and farming practices will be a key solution to the productivity and sustainability of global food production.

The current trend in electronic systems enables agriculture to enter a new era with the capability of real time data transmission and tasks monitoring. This adaption of electronic data acquisition systems has provided growers an accurate and essential information about field operations and enhanced the ability of ensuring optimal solutions (Darr, 2012; Webster, 2011).

Farm Management Information Systems (FMIS) are a new and evolving data processing and recordkeeping technology. This technology can be used effectively to capture, treat, store, and manage digital field information to enable and support farmers to make better decisions (Boehlje et al., 1984; Sorensen et al., 2010).

Developing and adopting modern technologies such as data logging systems is a critical element in supplying precise information about the agricultural machinery performance (Aubert et al., 2012; Fountas et al., 2006). Data logging systems are one of the most crucial technologies to provide operators with physical quantities. These measurements help operators evaluate, analyze, and manage the performance of machines in various field conditions when using data acquisition systems.

Some researchers identified a progressive advancement was developed in data acquisition systems for monitoring the performance and activities of agricultural tractors. This innovative approach created a focus for researchers to utilize it in order to better manage machines. Data acquisition systems (DAQ) have a crucial role in measuring and visualizing information of agricultural vehicles. For example, DAQ systems help maintain high levels of optimization through adjusting the operation of performance activities of engine load, engine speed, fuel consumption, vehicle location, radar speed, time, engine temperature, fuel temperature, etc. (Al-Janobi et al., 1997; Green et al., 1985; Grevis-James et al., 1983).

Demands for larger agricultural machinery to cover larger areas and developments in software have created opportunity for new techniques to help connecting sensors and modules without point to point wires. This protocol allows linking nodes together and enables exchanging real time information by using a common cable. This techniques enables performance evaluation of their machines versus older, less-accurate, manual methods. Controller Area Network (CAN) technology can be used to design management systems for global agricultural operations and designated tasks. The CAN Bus is widely used by automobile and agricultural equipment manufacturers. CAN Bus is a combination package of hardware and software to collect, process, analyze, visualize, store, and retrieve data. Ultimately, CAN technology and data structure configurations provide farm owners with accurate and succinct data giving them the ability to integrate and manage performance of agricultural machines as well as improve production processes. These configurations can also archive information about field operation tasks; thus, CAN Bus can also help farm owner oversee machinery work processes, visualize data, and establish optimal decisions (Speckmann et al., 1999) Beside agriculture, Controller Are Network (CAN) Bus became a widespread technology in marine, military, industry, medical and building automation (Darr, 2007; Çenesİz et al., 2004).

## 2.2 Introduction

CAN is the acronym for Controller Area Network which was originally developed by Robert Bosch GmbH’s company in 1986 for automobile in-vehicle data networks. As the name implies, Controller Area Network means that controllers (microcontroller) are connected in a network such as computers connected to a network. Electronic Control Units (ECUs), modules, and sensors attach to the main network wire using a Bus topology and exchange information between themselves.

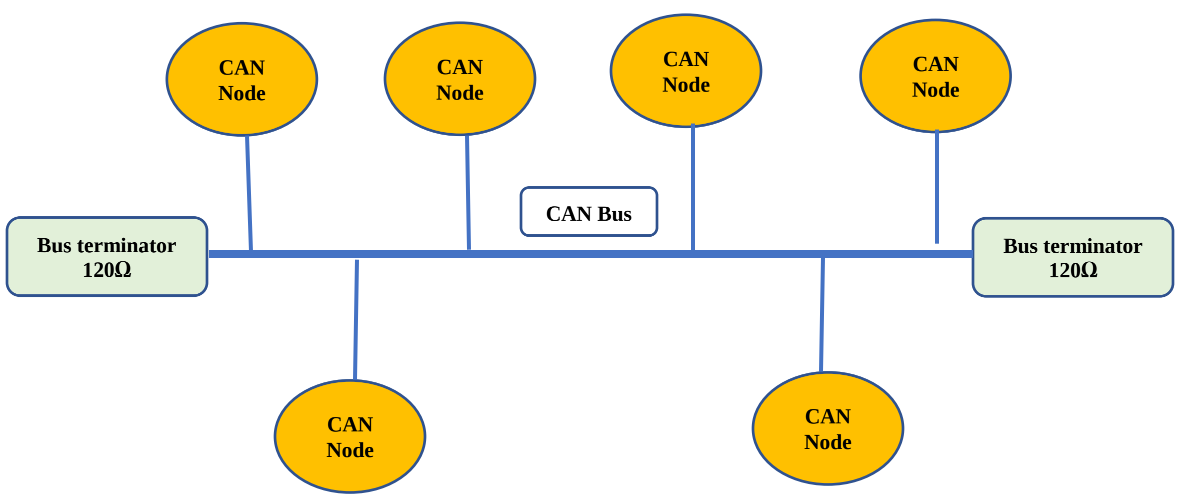


Figure 2.1. CAN Bus Network Basic Structure (Darr, 2017).

Basically, bus layout (topology) has one main cable that links all units and devices (Figure 2.1). The main cable in bus topology has 120 ohm (Ω) termination resistor at the extreme end of the cable to prevent signal reflections. This bus topology has many advantages compared to tree, star, line, and ring topologies. Advantages include ease of installation, low cost, and the robustness to node failure as it does not affect the other devices. The purpose of the CAN bus is to reduce wiring and provide communication between different ECUs and the operator, through the CAN-based display. Every ECU transmits and receives data over the same lines. Bus topology has a very simple harness instead of conventional wiring methods, which reduces installation costs for devices such as switches, pushbuttons, display equipment, and regulators. CAN Bus technology has an arbitration feature which prioritizes messages transmitted simultaneously so that the smallest arbitration number is dominant and takes priority over large ones eliminates data conflicts (Etschberger, 2001). Therefore, CAN Bus is used for high level communication protocols, manufacturing industries, and different fields such as handling, building, food processing, medical apparatus, and agriculture. Nowadays, “field bus systems” are largely used in agricultural machinery, of which single machine has 12 to 20 electronic control units that are sharing data. Additionally, CAN Bus enables exchange of real-time control signals for controlling machine operation (Darr, 2012; Lin, 2014; Udompetaikul et al., 2011).

In bus topology, which CAN uses, ECUs/nodes are connected such that if one node dies, it will not effect the communication to others. Each of these nodes can transmit, and all other nodes can receive in a certain order. A typical CAN node has basically three parts: a CAN transceiver, a CAN controller, and a microcontroller. The basic job of the CAN transceiver is to take the signal level from the bus and convert it to the signal level of what CAN controller is expecting. The microcontroller works as an ECU while the CAN controller decides which address to which the message should go.

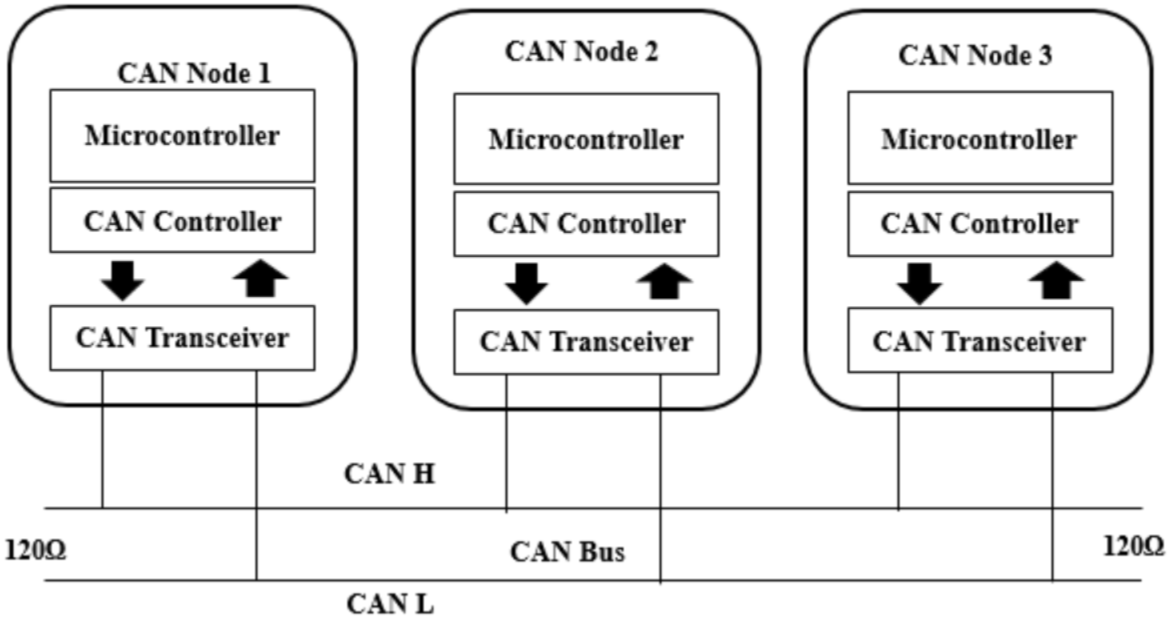


Figure 2.2. Schematic illustration of a CAN system consisting of three devices (nodes).

## 2.3 Architecture Layers

CAN is a widespread serial bus system that broadcasts digital bus information for many industrial applications. CAN is simply a two-wire interface that replaces point to point connections between devices. This bus enables real-time data exchange between control units and nodes. The first specification version of CAN protocol was published as a paper at SAE in February 1986. This specification version was extended to two compatible formats which are 2.0A and 2.0B versions. CAN 2.0A specification with a base frame format provides 11-bit message identifiers and the 2.0B extended frame format provides 29- bit message identifiers (Figures 2.3 and 2.4). The bit rate signal quality of the CAN system depends on the bus length. The shorter the bus length, the higher the speed of the signal (Darr, 2017).

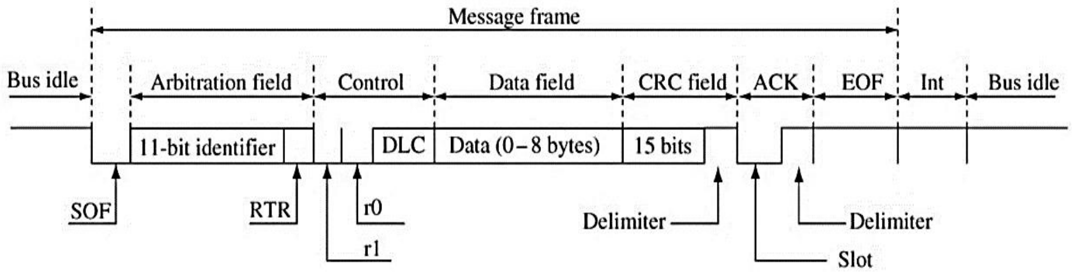


Figure 2.3. CAN 2.0A message frame (Çenesİz et al., 2004).

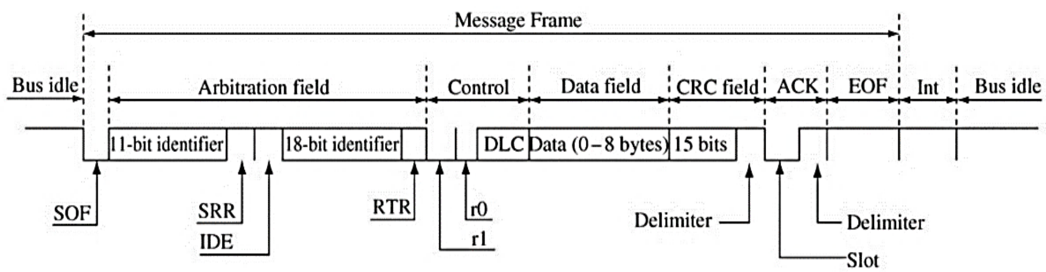


Figure 2.4. CAN 2.0B message frame (Çenesİz et al., 2004).

### 2.3.1 Physical Layer

The physical layer of this technology embraces the CAN standards SAE J1939 and ISO 11783 for agricultural and forestry applications. SAE J1939 is an auto standard that defines CAN data interpretation, and ISO11783/ISO bus is an agricultural standard which builds on J1939. ISO11783 provides additional data interpretation standard for agricultural vehicles

ISO 11898 subdivides the physical layer into three different sublayers PMA (Physical Medium Attachment), MDI (Medium Dependent Interface), and PLS (Physical Signaling). The purpose of the physical layer is to transmit the bits from one node to another through two twisted wire pairs. Further, the physical layer is responsible for bit timing, bit coding, bit synchronization, etc. CAN protocol operates at 5 VDC and the data rate for CAN –high is 1 Mbit/s which runs at voltage rate of 2.5 V to 4 V. Whereas the data rate for CAN–low is 125 kbit/s and runs at a voltage rate of 1 V to 2.5 V ( Darr, 2017). The difference result between CAN high (CAN–H) voltage and CAN low (CAN–L) voltage forms two logic state levels which are dominant (active, logical 0, or power on) and recessive (passive, logical 1, or power off). If there are more than one message transmitted between stations and there is a collision between the aforementioned two states, the dominant state should occur on the bus. That means the higher priority is accompanied with the lower number.

The dominant state condition occurs when the differential voltage of the receiver's input is less than 0.5 V and the differential voltage of the transmitter is less than 1.5 V. If one case at least has been violated, the state will be a dominant bit (Di et al., 2012; Darr, 2017). Physically, the CAN Bus is consists of two wires "green and yellow".

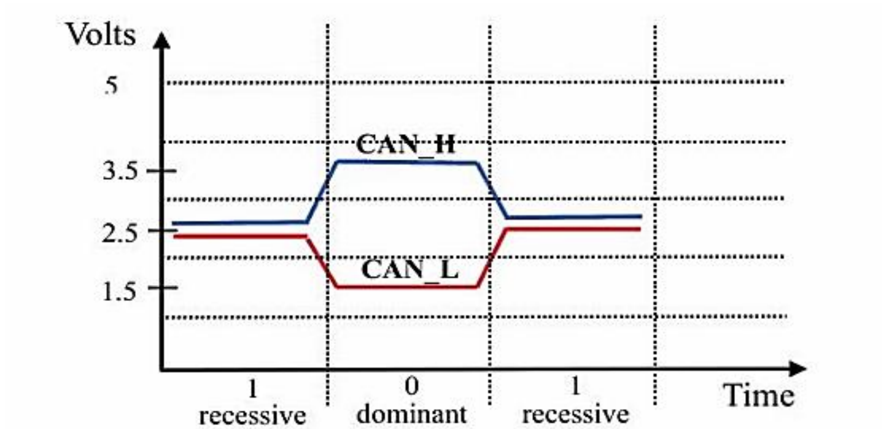


Figure 2.5. CAN bit stream"101" (Darr, 2017).

## 2.4 Message Frame Structure

As mentioned earlier, CAN Bus is a broadcast type of bus. The communication protocol uses short messages to link nodes. There are four different message-frame structures (frames) in CAN protocol for message transmission or reception: data frame, remote frame, error frame, and overload frame. Only the data frame is used when nodes transmit data on the network.

### 2.4.1 Data Frame

The data frame is the most common message type. It consists of seven distinct embedded fields that convey further data about messages. These fields are: Start of Field (SOF), Arbitration Field, Control Field, Data Field, Cyclic Redundancy Code (CRC) Field, Acknowledgment (ACK) Field, and End of Frame Field (EOF). The function of data frame is to broadcast data between transmitters and receivers without addressing the targeted station. As mentioned earlier, based on the Identifier Field, there are two types of CAN messages: standard frames with 11 bits and extended frames with 29 bits. Both frames can be broadcasted on the bus. The actual data of the message is distributed through data frame from devices to all nodes or Electronic Control Units (ECUs) on the network system (Di et al., 2012).

The Data frame is the most common frame in the message frame, and it includes SOF, Arbitration Field, Control Field, Data Field, CRC Field, ACK Field, and EOF Field.

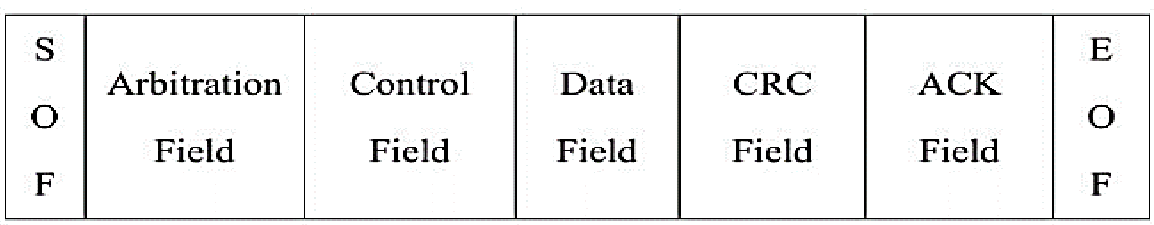


Figure 2.6. Structure of a Data Frame (Darr, 2017).

#### 2.4.1.1 SOF (Start of Frame)

This field always starts with a single dominant bit represented as logic 0. SOF denotes the start of any CAN frame and provides a falling edge for hard synchronization of the transmitter and receiver.

#### 2.4.1.2 Arbitration Field

The CAN Bus communication protocol uses CAN arbitration to manage simultaneously transmitted messages. The arbitration field determines the priority of the message when two or more nodes are contending for the bus at the same time. The number being broadcast in the arbitration field by multiple ECU are compared and the smallest number is dominant. The ECU with that smallest number takes and allowed to continue sending its priority message over the other ECU which have large number. The Arbitration Field consists of two components which are the identifier and Remote Transmission Request (RTR). RTR enables the ECU to distinguish whether the frame contains a Data Frame or a Remote Frame. If the RTR is set to dominant, the Data Frame contains data. If RTR bit is set as recessive, the message is a Remote Frame (Di et al., 2012).

The Arbitration Field can have two different arrangements depending on the Protocol Data Unit (PDU) format. If the PDU format number is between 0 and 239, it is a PDU1 format. and comprised of a priority level, Parameter Group Number (PGN), destination address (DA), and source address (SA). For a (PDU) format number between 240 and 255 it is a PDU2 format and is composed of priority level, PGN, and source address (ÇenesİZ et al., 2004).

#### 2.4.1.3 Control Field

The Control Field consists of six bit components providing the number of data bytes to be broadcasted and whether the message is a standard frame or extended one. The first 2 bits are Identifier Extension Flag (IDE) bits, and the last four bits define the length of the data as Data Length Code (DLC). In the standard format, the IDE is dominant; while in the extended format, it is recessive.

#### 2.4.1.4 Data Field

Data Field consists of 0-8 bytes (0-64 bits) of data that embedded the actual data of the message broadcasted with the most significant bit (MSB).

#### 2.4.1.5 Acknowledgment (ACK) Field

As the name states, the Acknowledgement (ACK) Field is used to ensure that the message was successfully delivered. Acknowledgement field includes two bits which are ACK slot and ACK delimiter. Any CAN controller that has been able to correctly receive the message sends an Acknowledgment bit at the end of each message. The transmitter checks for the presence of the Acknowledge bit and transmits the message if no acknowledge was detected (Etschberger, 2001).

If the node has received a correct message from the bus, a dominant bit will be inserted in the ACK slot acknowledging message reception from the sender. Otherwise, the receiver will not return any acknowledgment signals to the transmitter because of a possible error. ACK delimiter, is always transmitted recessively (high) for the purpose of error detection.

#### 2.4.1.6 End of Frame (EOF)

End of Frame consists of seven high (recessive) bits and marks the end of the data frame.

### 2.4.2 Remote Frame

A Remote Frame requests the transmission of data from other nodes. It is composed of six different bit fields: start of frame, arbitration field, control field, CRC field, ACK field, and End of frame. The CAN remote frame has the same structure like CAN data frame with the following two differences: RTR bit of the arbitration field is of recessive value, and data field does not exist at all.

### 2.4.3 Error Frame

An Error Frame is a special message that violates the framing rules of a CAN message. The function of Error Frame is to transmit an error frame in case of any error detection. Error Frame includes two fields: Error Flag (active and passive) and error delimiter. An Active Error Flag has a series of six consecutive dominant bits while the passive has six recessive bits and the error delimiter has eight recessive bits. ECU’s with errors can be identified by the source address (SA) included in the error message (Etschberger, 2001).

### 2.4.4 Overload Frame

The Overload Frame includes six consecutive dominant bits and the purpose of this frame is to provide a waiting time as a delay time between messages. This delay time enables the nodes to process preceding data and receive the new frame.

## 2.5 How CAN Communication Works

In a CAN Bus system, multiple nodes communicate with each other through transmitting messages to target nodes based on specified identifiers. All nodes function as masters. This configuration means there is no master controller that supervises the bus. This configuration ensures more robust connection as well as fault reduction. The bus network topology of CAN Bus reduces the points of failure, since a single data line is used to handle all communications. Further, nodes branch out from the main line, this means if one node fails it does not affect any other nodes in the system nor affects the functionality of the main bus. Such topology makes it easier to monitor faults and diagnose specific problems, rather than having to manually query numerous sub-controllers distributed throughout the system.

CAN protocol includes bitwise arbitration messages that are arbitrated through the ECU priority embedded controller. Transmitted messages are not assigned from node to another, instead, all units on the network communicate with each other. This arbitration structure in the linking system allows high priority messages to be transmitted before low priority messages as well as helps prevent time delays (Pfeiffer et al., 2008; Etschberger, 2001).

CAPL, or CAN Access Programming Language, is a programming language within CANoe used to automate CAN test and measurement functions. CAPL simplifies analyzing tasks and allows for easy playback of CAN logs. This language is based upon the C programming language (Darr, 2017).

## 2.6 CAN Communication Standards

Currently a typical agricultural machine has 12 to 20 ECUs that communicate with each other to exchange data based the operation of the machine. This wide range of signals and exchange data enables the operator to broaden their understanding of machine performance

(Darr, 2012; Pitla et al., 2014). The J1939 standard was introduced to create a uniform set of common messages, enabling a modular approach and standard tools for logging and decoding across manufacturers.

The SAE J1939 database supports labeling CAN messages as sensible information humans can comprehend as well as configuring CAN Data frames. In SAE J1939, CAN raw data, which comes in a hexadecimal format, is formatted into physical engineering units which portray the useful information operators are interested in. In other words, the use of the SAE J1939 database allows the scientific community to easily access important machine operating parameters which help increase confidence in research and management decisions (Pfeiffer et al., 2008).

International Standard Organization (ISO) and the Society of Automotive Engineering (SAE) have worked jointly to create some protocols to ease system communications. These international standards are categorized for high-speed implementation (ISO 11898), low-speed implementations (ISO 11519), and J1939 for CAN based protocols which is the same function of using protocol layers of ISO 11783. In 1993, SAE J1939 was targeted for agricultural machinery and heavy-duty vehicles messages. J1939 offers a standardized method for communication across ECUs as a one language across manufacturers. These messages were expected to be communicated and transmitted on the system without a particular destination. The data from SAE J1939 CAN Bus transmissions can be recorded by different instruments manufactured by Vector, Kvaser, and National Instruments (NI). This diversity of CAN Bus logging and conversion methods and devices could likely influence studies that target the J1939 database. Determining the optimum data collection tools among these options depends on file size and signal convertibility.

Below (Table 2.1) are some calculated examples and the most common signals and messages in J1939 (Darr, 2017).

Table 2.1 Signals and messages examples details in J1939.

| | Signal | PGN (hex) | PGN | Position (bit #) | Bits/ DLC | Resolution. | Range | Units | Offset. |
|---|---|---|---|---|---|---|---|---|---|
| **Engine Speed** | **EEC1** | F004 | 61444 | 4-5 | 16/8 | 0.125 | 0 - 8,031.875 | RPM/bit | 0 |
| **PTO Speed** | **RPTO** | FE43 | 65091 | 1-2 | 16/8 | 0.125 | 0 - 8,031.875 | RPM/bit | 0 |
| **Ground Speed** | **GBSD** | FE48 | 65097 | 1-2 | 16/8 | 0.001 | 0 – 64,255 | (m/s)/bit | 0 |
| **Fuel Rate** | **LFE** | FEF2 | 65266 | 1-2 | 16/8 | 0.05 | 0 – 3,212.75 | L/hr | 0 |
| **Fuel Level** | **DD** | FEFC | 65276 | 2 | 8/8 | 0.4 | 0 – 100 | % | 0 |
| **Engine Hours** | **Hours** | FEE5 | 65253 | 1-4 | 32/8 | 0.05 | 0 – 210,554, 060.75 | Hrs | 0 |

<u>Engine Speed:</u>
Data F0 FF 8D <u>20</u> <u>1C</u> FF FF FF 0x 1C 20
Hex to dec 1C = 28 20 = 32
= (28 *256) + 32 = 7200 bits
= 7200 * 0.125 rpm/bit +0 (offset)
= 900 rpm

<u>Ground Speed:</u>
Data <u>00</u> <u>00</u> E5 D9 21 00 FF FF 0x 00 00
Hex to dec 00 = 0 00 = 0
= (0 *256) + 0 = 0 bits
= 0 * 0.001 + 0 (offset)
= 0 m/s

PTO Speed:

| | | |
|---|---|---|
| Data | C0 0D FF FF 5D FF FF FF | 0x 0D C0 |
| Hex to dec | 0D = 13 C0 = 192 | |
| | = (13 *256) + 192 = 3520 bits | |
| | = 3520 * 0.125 rpm/bit + 0 (offset) | |
| | = 440 rpm | |

Fuel Rate:

| | | |
|---|---|---|
| Data | 5A 00 FF FF FF FF FF FF | 0x 00 5A |
| Hex to dec | 00=0 5A=90 | |
| | = (0 *256) + 90 = 90 bits | |
| | =90 * 0.005 l/h/bit +0 (offset) | |
| | = 4.5 l/h | |

Engine Hours:

| | | |
|---|---|---|
| Data | EE 07 00 00 FF FF FF FF | 00 00 07 EE |
| Hex to dec | 00=0 07=7 EE=238 | |
| | = 0*256^3 + 0*256^2 + 7*256^1+ 238*256^0 = 2030 | |
| | = 2030 * Resolution + Offset | |
| | = 2030 * 0.05 + 0 | |
| | = 101.5 hours | |

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# CHAPTER 3. THE PERFORMANCE OF FARM TRACTORS AS REPORTED BY CAN-BUS MESSAGES, TILLAGE PROJECT

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## 3.1 Abstract

Tractors and agricultural machinery have been designed specifically for land preparation, tillage, and other agricultural operation tasks. Tractors are the primary source of power in farms and fields. To obtain the optimum output from them, proper management and utilization is needed. Agricultural machinery performance has been studied over the past three decades. Results have been obtained for different configurations of agricultural machinery. In general, the evaluation of agricultural machinery, using traditional methods, is problematic as they are time consuming and labor intensive. Moreover, by using common evaluation methods, it is typically difficult to obtain accurate and immediate results. Accurate measurements of field performance parameters are required for monitoring machinery performance and management decisions. Recently, improvements in electronics technology have made field operational management easier to monitor. For example, Controller Area Network (CAN) Bus technology is being used as a communication system in tractors and allows connections between Electrical Control Units (ECU). CAN Bus technology broadcast unique electronic messages which contain continuously updated information about the engine, power train,

equipment, power take off, hydraulic system, and other parts of machines. To evaluate the performance of agricultural machinery, there is no longer a need for myriad measurement instruments producing widely varying output to individually measuring fuel consumption for each speed, gear shift and the whole operation. This study was conducted to evaluate tractor performance by CAN Bus technology as a simple to use, easy to install, high speed data collection, and convenient method to retrieve stored data. These techniques allow for substantial saving of money and time, reducing our workload and eliminating training necessary for specialized measurement tools. Results have been demonstrated through a case study analysis of field cultivator under multiple tractor and implement configurations. The study was conducted in a 41 hectares field near Ames, Iowa, United States. The results show that there is a significant difference in fuel consumption ($P<0.05$) due to engine power, tillage depth, tire inflation pressure and the interaction between tillage depth and engine power. However, after adjusting for multiple comparison, there was no significant difference ($P<0.05$) between depth 7.62 and 12.7 cm (86.21 L/h and 87.05 L/h respectively) on maximum power. In contrast, there was a significant difference observed at low power for depth 7.62 and 12.7 cm. Additionally, a significance difference within depth was observed between maximum and 70% power. At depth 7.62 cm, the fuel rate for the maximum power is found to be 86.21 L/h while for 70% power was 67.58 L/h. It is clear that increasing tillage depth associated with increasing soil disturbed volume leads to increased tractor load and fuel consumption to pull the implement. In addition, at the standard weight the maximum fuel consumption (87.24 L/h) was observed at maximum power with a maximum depth (12.7 cm) and maximum tire pressure. Likewise, for the same weight, low fuel consumption (67.04 L/h) was observed at 70% power in low depth (7.62 cm) at low tire inflation pressure. Moreover, in adding weight, the maximum fuel rate was observed at maximum power and higher depth (12.7 cm) at high tire inflation pressure. While low fuel consumption was observed at low power in low depth (7.62 cm) and low tire inflation pressure. The results also show that the engine power usage is not significant on fuel rate consumption. Additionally, the higher slippage percentage is found to occur at lower power usage and higher tillage depth. Moreover, for the added weight, the highest slippage percentage (19.80%) was observed at maximum tire inflation pressure, higher depth (12.7 cm) and low power (70%). While the lowest slippage percentage was observed at low tire pressure, low tillage depth and 70% power usage. As a result, this study was conducted to evaluate tractor performance by CAN Bus technology as a simple to use, easy to install, high speed data collection, and convenient to retrieve the stored data. These techniques allow for substantial saving of money and time, reducing our workload, eliminating training necessary for specialized measurement tools, and improving agricultural machine management.

## 3.2 Introduction

Agricultural machinery plays an important role in the performance, productivity, and costs of agricultural operations. During recent decades, agricultural machines have been developed to reduce labor costs as well as improve the timeliness of field operations (Schäfer-Landefeld et al., 2004). Moreover, agricultural machine efficiencies have a significant effect on yields, which in turn impact overall production costs (Pitla et al., 2014).

Tillage is among the most important operations in agriculture. It is defined as “the changing of soil condition for the enhancement of crop production” (ASABE Standards, 2009). Tilling the soil produces ideal soil conditions by improving the relationship between air and water for crop growth (Busscher et al., 2003; Gill et al., 1967; Osunbitan et al., 2005).

However, many studies show tillage consumes at least half of the engine power to operate an implement and around 30 percent of the total power consumption in agricultural operation (Pass, 1979). This has led many farmers to become more concerned about tillage and, seek new methods to reach optimum production by substituting human power with mechanical power (Ahaneku et al., 2011).

Tillage can be classified as primary or secondary. Primary tillage constitutes the initial major soil working operation. It is normally designed to reduce soil strength, cover plant materials, and rearrange aggregates. Secondary tillage occurs at a shallower soil depth than primary tillage. Its purposes are to (1) provide additional soil pulverization; (2) mix pesticides and fertilizers into the soil; and (3) level and firm the seed bed (ASABE Standard, 2005). The best example of secondary tillage is a field cultivator for seedbed preparation, weed eradication, and fallow cultivation subsequent to primary tillage (ASABE Standards, 2009). Hence, studying field parameters during tillage help the operator to manage their machines.

Tractors and agricultural machinery have been designed as a standard power source for land preparation, tillage, and other agricultural operational tasks. Tractors are the primary source to provide mechanical power to farms and fields (Kepner et al., 1978). To obtain the optimum output from them, good management and utilization should be applied. Tractor performance has been studied over the past three decades, and optimum results have been obtained for different agricultural machinery (Stombaugh et al., 2008). Having the most power converted from the engine to traction power enables lower energy consumption during an agricultural operation (Ahaneku et al., 2011). A study conducted by Sabanci (1997) found that 12.0 to 18.0% of the engine power was consumed before starting the operation. In addition, another 20.0 to 40.0% of power is lost between the axles and the ground (Mowitz et al., 1987).

Improper selection of tractor size can cause excessive operating costs. Knowing the parameters that affect efficiency can improve the performance of agricultural machinery (Sumner et al., 2007).

Moreover, despite the type of soil condition and tire design, other important parameters that affect tractor performance include implement size, practical speed, and depth of operation. These parameters can easily be managed and controlled by operators to obtain optimum performance. In addition, proper tire inflation pressure and appropriate ballasting weight are essential for evaluating and managing performance. According to Sümer et al (2005), obtaining the best performance with least cost, proper ballasting, and correct tire inflation must be adjusted. However, improper adjustments lead to fuel waste, tire wear, and drive train damage, and hence decreased productivity and efficiency (Stombaugh et al., 2008). Wulfsohn et al. (2009) found that ballasting and tire inflation pressure played a significant role in tractor fuel consumption and tractive performance. A tractive efficiency improvement of about 4% to 7% was obtained while using correct ballast with low-correct tire inflation pressure, as compared to overinflated tires  (Zoz et al., 1994). Likewise, as reported by Lancas et al. (1997), about 18% to 20% of fuel was saved when they used low-correct inflation pressure with regard to axle load.

The main performance indicators in tillage operations are fuel consumption, slippage percentage, engine percent load, engine cooling systems, and fuel temperature. Fuel consumption is considered the most important factor for research in agricultural operations, and testing and assessing the performance of machines. According to Hanna, (2001) and Thakare et al., (2009), fuel consumption is affected by a number of factors such as soil type and moisture, the users, tractor design (two wheels or four wheels), tractor size, equipment width, working depth, and speed of operation. Likewise, mentioned by Bukhari et al. (1982), fuel consumption depends on different variables such as width and depth of cut, and speed and kind of operation.

Fuel consumption can be measured with either a direct or indirect method. The direct method is accomplished by comparing the level of fuel in the tank before and after the operation. The indirect method is determined by using a graduated cylinder located between the tank and the fuel injection pump to measure the consumed fuel (Natsis et al., 1999). Additionally, fuel rate can be measured by using fuel meter (Wald, 1968). Field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed in percent.

In addition, to measure and monitor mechanization unit performance, enumerable systems have been developed to determine tractor performance monitoring and optimization (TPMO). However, the majority of these systems were not fully adequate. The best example of this system is Controller Area Network (CAN) Bus technology developed by Mercedes Corporation (Voss, 2008). This technology is a communication system in vehicles that allows connections between multiple Electrical Control Units (ECU). Improvements in electronics technology have made field operation easier to monitor. This new CAN Bus technology is becoming widely used in agriculture to help farmers determine and improve field efficiency, while decreasing equipment costs (Darr, 2012). CAN messages depend on the broadcast system and can be filtered based on the requirment. These messages are continuously updating information about the engine, power train, equipment, power take off, and hydraulic system (Darr, 2017).

According to The United Nations, the Gross Domestic Production (GDP) for some countries has declined. This degradation in agricultural production provides motivation to increase agricultural machinery performance. Efficiency and accuracy of field operations are best required solution in order to reduce the shortfall in food production system and as an essential element to maximizing machinery performance. The fact that there is a limited progress in agricultural mechanization sector impact the agricultural production in a significant portion. Testing and evaluating agriculture machinery using updated technologies and techniques is a key contribution in farm production. Till these days, there are some places that using a traditional methods in measuring the performance of agricultural machinery (Figures 3.1 to 3.4). The technology like CAN Bus will help to increase efficiency by monitoring machine performance and reduce production costs.

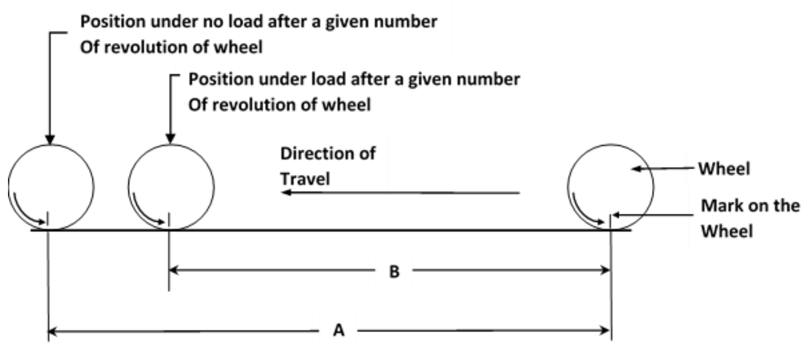



Figure 3.1. Wheel slip measurement.

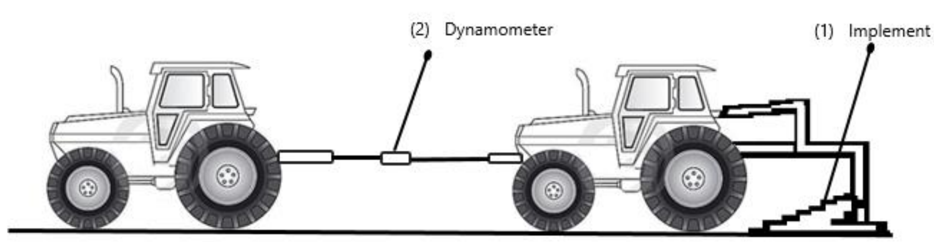



Figure 3.2. Draft measurement for a tractor and implement.

Figure 3.3. Traditional cultivation.

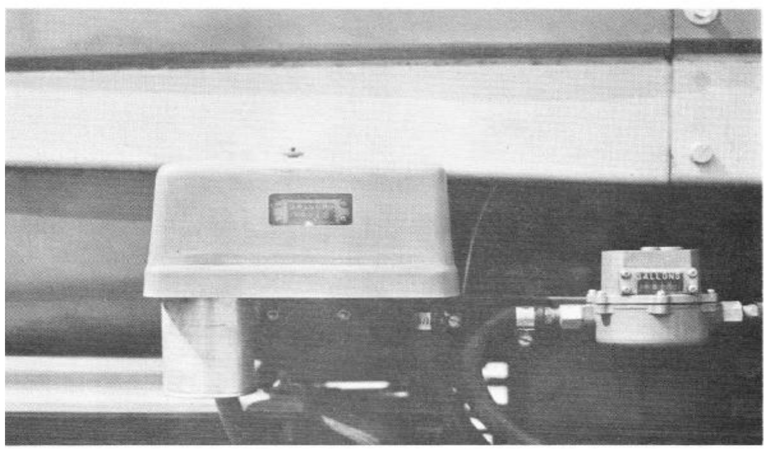


Figure 3.4. Fuel meter for fuel consumption measurement (Wald, 1968).

## 3.3 Objectives

The objective of this study was to demonstrate the capabilities of a CAN Bus based evaluation system for quantifying key performance indicators for an agricultural tillage operation. Results will be demonstrated through a case study analysis of field cultivation under multiple tractor and implement configurations.

## 3.4 Literature Review

Soil preparation operations, such as tillage, are one of the very important issues in reducing production costs and speed up the completion of the agricultural operations as well as reducing labor requirements. Therefore, the literature review in this study about tillage will be mainly focused on the following topics to assess many management practices:

1. Fuel consumption
2. Slippage Percentage
3. Efficiency

### 3.4.1 Fuel Consumption

Due to a high escalation of oil products and decreasing in total net farm income, improving field efficiency has become a considerable issue for the majority of agricultural producers. Fuel consumption per tilled area is a very important indicator of agriculture machine performance. There are a number of different agricultural factors affecting the fuel consumption of the tractor such as soil type and moisture, the user, tractor type (two-wheel drive, four-wheel drive), tractor size, equipment width, working depth, and speed of the operation (Hanna, 2001; Thakare et al., 2009). Therefore, the values of the fuel consumption of the tractor measured in different ways are not constant, but vary from one test to another. Bukhari and Baloch (1982) concluded that fuel consumption depends on different variables such as: soil type, soil moisture, width and depth of cut, and speed and kind of operation. Maximizing fuel efficiency is one of the important elements for evaluating the tractor performance and for reducing fuel consumption (Grisso et al., 2008; Wu et al., 1986).

According to Siemens et al. (1999), the cost of fuel and labor range from 16% to over 45% of the total machine cost depending on operation time and fuel type. Natsis et al. (1999)

stated that fuel consumption of the tractor engine can be measured by using either a direct way or indirect way. The first method is done by measuring the level of fuel in the tank before and after the test procedure, but there are some errors in this way, especially when the test is short time and small area. The second way is done by using a graduated cylinder located between the tank and the fuel injection pump to measure the consumed fuel. According to Piloca et al. (2010), the research data shows that in order to increase 1% in agricultural production, fuel consumption needs to be increased by 2.5%.

#### 3.4.1.1 Factors affecting fuel consumption

Fuel consumption has been a big consideration for food producers because it is directly linked to consumers and it is significant key of food supplies. Several methods have been developed for optimizing energy consumption on fields. Best agricultural practices are one way to optimize working efficiency and save energy which leads to lower production costs. Tractor fuel consumption depends on several factors such as speed, specifications, slip, etc.

Traveling speed play a very important role in determining the required fuel consumption. (Woerman et al., 1984) found that there is a strong relationship between increasing the forward speed and slip.

A series of tests was showed by Moitzi et al. (2006) that each one centimeter in ploughing operation consumes from 0.5 to 1.5 l/ha. Fathollahzadeh et al. (2009) concluded that fuel consumption was increased by 25% when there is 8 cm increase in working depth of the plough. Increasing the working depth will increase the draft requirement for the implements and that will cause a significant increase in slippage (Muro et al., 1999).

A best possible performance can be achieved by studying agricultural mechanization and automation and making proper adjustments. A number of tests were conducted for different implements by Sumner et al. (1986) which show there is a significant increase in fuel consumption when the loads were raised. Similarly, tractor fuel efficiency improved by choosing correct combination of tire inflation pressure and ballast (Serrano et al., 2009). Goyal et al. (2010) observed a significant fuel consumption when increasing the depth of plowing. A fuel consumption increased with increases in load. The same pattern was obtained when Lancas et al. (1997) carried out an experiment and concluded that 18% to 20 % of the fuel can be obtained when using the low-correct tire inflation pressure.

Wheel slip affects fuel consumption of tractor significantly. (Schutte et al., 2004) reported that there is a strong relationship between tractor fuel consumption and the travel reduction ratio. Under certain circumstances with a heavy cultivator, 2 l/ha was saved in fuel consumption while reducing wheel slip from 15% to 5% (Moitzi et al., 2006). In addition to engine speed and gear ratio, operating speed influences fuel consumption. (Schutte et al., 2004; Wu et al., 1986).

### 3.4.2 Slippage Percentage

Wheel “Slip” or “Slip percentage” has been known as travel reduction; however, these are not equivalent terms**.** Slip happens between surfaces while travel reduction is a decrease in distance or speed (Brixius et al., 1978). The overall tractor efficiency can only be optimized by raising its tractive efficiency. For best work conditions, appropriate and accurate measurement of slip is a key factor for proper management of the automation field. To optimize and adjust wheel slip, operator could add weights, change the air pressure, add duals, or change the tires.

#### 3.4.2.1 Factors affecting slip

Problems of wheel slip percentage are mainly caused by machinery operation. It is important for operator to know what the suitable wheel slip should be for the tractor operation. In general, both too much and too little wheel slip are undesired outcomes (Birrell, 2017).

The tractor-implement forward speed is a key parameter for determining the performance of agricultural machinery in the field. However, tractor practical speed is a fallible element. With the continuous magnitude of agricultural machinery power and size to accomplish the designated tasks in field activities, it is likely that errors would increase.

A paradigm shift in agricultural technologies in addition to equipment upsizing has been increasing farm managers' consideration about management practices. For better utilization of agricultural machinery, It is important to observe wheel slip in order to determine how best to adjust the set up the tractor. These adjustment could be ballast or tire pressures.

More recently, the continuous development of mechanization and automation in agricultural machinery has led to the need for relatively large equipment to be used. The expansion of tractor population and increasing their power prioritize operators' objectives to well controlled and managed machines.

In general, to obtain optimum performance from the tractor, the correct tire inflation pressure for each tire loaded and must be checked and adjusted based on load, speed, and ground surface conditions (Zoz & Turner, 1994).

### 3.4.3 Field Efficiency

Field efficiency [Ef] is the ratio of effective field capacity to theoretical field capacity, expressed in percent. It is the comparison between the amount of power consumed by the machine to the amount that should be consumed. Any change in width or speed will cause a decrease in field efficiency. Theoretical field capacity [TFC] is the rate of performance obtained if a machine performs its function 100% of the time at a given operating speed using 100% of its theoretical width. Effective field capacity [EFC] is the actual rate of land or crop processed in a given time. The capacity of agricultural machinery can be determined by productivity (Roth et al., 1995).

Developing productivity is the most widely example of farm owners are concerned about and still a great challenge to them. However, these outputs help them manage their fields by changing management practices based on monitored data. Increasing the agricultural areas with relatively large agricultural machinery should continue to combine with technologies and investments enabling operators to manage the resources accurately and maximize farm profitability.

Shifting from mechanical application of yesterday mechanization to the advance of new technologies coupled with communication systems has become widespread. Such communication can help to build a network by connecting working vehicles in the field and transfer the performance date to the office instantly. These imperative capabilities ensure farm operators will manage the tasks easily.  To maximize tractor efficiency in the field, operator or owner can adjust tire pressure and ballast weight according to different operation task.

#### 3.4.3.1 Factors effecting efficiency

Agricultural machinery has been improving over the past couple of decades. However, the trend toward increasing the working speed to cover many more areas with the same machine is another consideration of the operators. Field speed is considered as an important factor for evaluating tractors and agricultural machinery (Al-Aani, 2000). Hence, it gained a special importance from farmers and applicants.

Operating speed influences the productivity of agricultural machinery. The accomplished work of the tractor has had a unique importance to farmers and field advisors. Zoz et al. (2003) Indicated that the operating speed had a significant effect on productivity and efficiency.

To advise and assist farmers in the choice of applicability of machines and tractors, working width and depth have a unique importance. Several different methodologies in the field should be followed to gain the optimum efficiencies from the working equipment.

The optimum configuration is an essential requirement for efficient performance. There are, however, several challenges to determine the best condition for work. Developing a correct technique can increase the performance of agricultural machinery through the assessment of many management practices. Inexperienced operators often work inefficiently by improperly using the machines, which can cause severe extra negative effects to the whole farm. Many researchers have discussed the effects of reduced tire inflation pressure and wheel load configuration on tractor performance. Dwyer (1984) have studied the effect of adding more weight on the front axles and how that increased efficiencies for the soft soils.

Wheel slip is an important element and fundamental to determine the performance of agricultural mechanization. Several different technologies and skills can be used to determine slippage percentage.

To perform better, operator should ensure that tractors are operated correctly. “gear up and throttle down” method implemented to increase fuel efficiency through operating the throttle properly. This method allows the operator to utilize the highest gear that the tractor allows without overloading the engine.

## 3.5 Materials and Methods

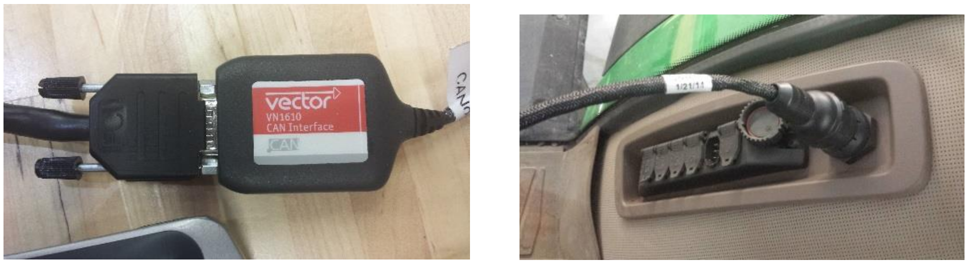
### 3.5.1 Field Equipment and Data Collection

This study was conducted in a field in Ames, Iowa, United States in March 2016. The field has approximately 41 hectares and the previous crop was soybeans (Figure 3.2 a). The field soil type was Webster clay loam with 0 to 2% slopes. CAN Bus data were obtained from the International Standard Organization (ISO) diagnostic port of a four-wheel drive (4WD) tractor (9430, 425 hp, 43500 lb John Deere) to collect and monitor the performance of the unit. The tractor static weight distribution was 53.20% on the front axle and 46.45% on the rear axle and all tires were Firestone Dual 710/70 R42. The implement used in all testing was a 15.54 m (51 ft) wide field cultivator (model 2210, 25500 lb John Deere) which was representative of tillage implements commonly used for seedbed preparation in the region (Figure 3.2 b).

(a) (b)

Figure 3.2. (a) The 41 hectare Soybean field (b) John Deere (9430) and field cultivator.

A CAN Bus analyzer (Vector VN 1610) was used to collect messages from the tractor using a laptop computer through Universal Serial Bus (USB) as shown in Figure 3.3. Data were logged in an American Standard Code for Information Interchange (ASCII) file in real–time during field operations. In addition, a backup data set was recorded by using a Vector (GL1000) data logger for backup.




(a) (b)

Figure 3.3. (a) VN1610 Vector CAN Card (b) 9 Pin diagnostic to serial port.

The tractor CAN Bus was configured at 250 kb/sec and messages were recorded in hexadecimal format. The Society of Automotive Engineering (SAE) J1939 database protocol was used to decode the structure of the CAN message into PGN and data byte values (Darr, 2017). After collection, the raw ASCII CAN logs were uploaded to a Structured Query Language (SQL) database for data interrogation and management. Figure 3.4 demonstrates the Parameter Group Number (PGN) used for Engine Fuel Rate (PGN 0xFEF2) and for Engine Speed (PGN 0xF004). Moreover, the tractor was connected with a John Deere StarFire 3000 GPS receiver to provide geospatial position and GPS based speed information during the test. The key field performance indicators of the combination unit are fuel rate, slip percentage, and effective field capacity. Figure 3.5 shows the recorded CAN Bus signals during tests.

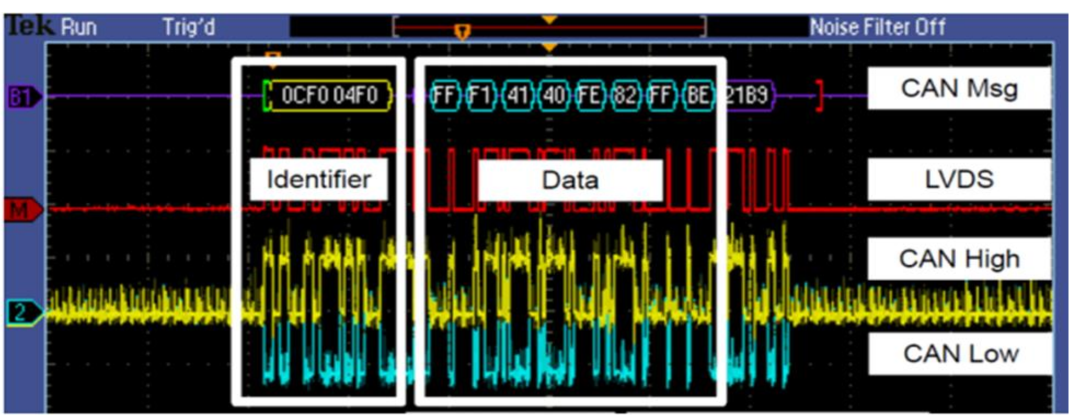



Figure 3.4. Message identifier and Parameter Group Number (PGN) Message (Darr, 2012).

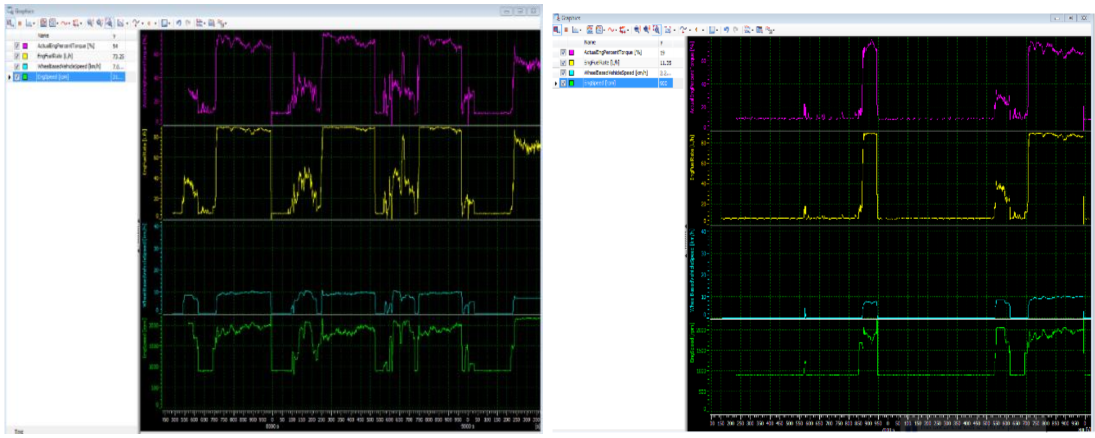


Figure 3.5. CAN Bus signals recorded during tests.

### 3.5.2 Key Performance Indicators

Field capacity (FC) is the rate of a machine's performance. It can be measured, depending on the type of the machine, as either ha/h or kg/h. Field capacity is an important parameter to determine machine selection and cost evaluation. Field efficiency can be classified as the ratio of effective field capacity (EFC) to theoretical field capacity (TCF). The TFC is described as the maximum rate of machine performance achieved by forward speed and complete implement width, expressed as ha/h (Equation 1).

$$\mathrm{TF} = \frac{(\mathrm{W} * \mathrm{S})}{10} \qquad (1)$$

Where

TFC = Theoretical Field Capacity (ha/h).

W = Implement width (m)

S = speed (km/h)

The Effective Field Capacity (EFC) is the actual rate of machine performance in regard to field efficiency, actual working width, and practical speed expressed as ha/h. The EFC can be determined using (Equation 2).

$$\mathrm{EFC} = \mathrm{TFC} * \mathrm{Ef} = \frac{\mathrm{S} * \mathrm{W} * \mathrm{Ef}}{10 * 100} \qquad (2)$$

Where

EFC = Effective Field Capacity (ha/h)

S = Practical speed (km/h)

W = Rated width of implement (m)

Ef = Field efficiency (%)

Field Efficiency (Ef) is the ratio of the effective field capacity to theoretical field capacity. Field efficiency can be improved by reducing lost time during operation, such as filling, unloading, turning, blocking, checking, repairing, and resting. Ef can be calculated using equation (3)

$$\mathrm{Ef} = \frac{\mathrm{EFC}}{\mathrm{TFC}} * 100\ \% \qquad (3)$$

### 3.5.3 Experimental Design

The study was arranged in Randomized Complete Block Design (RCBD) with four factors, two levels of each factor (explanatory variable), and three blocks per treatment. The field designated for the combination of tractor and field cultivator to perform the secondary tillage was divided into three blocks with 16 strips (treatment) per block for a total of 48 strips (one strip per treatment). The four factors were (1) tractor weight, (2) tractor tire inflation pressure, (3) tillage depth, and (4) percentage of engine power usage. The tire inflation pressure were set for 21- 22 psi (all tires) in the first level, and 10- 11 psi for the front tire and 7-8 Psi for the rear tire in the second treatment level. Two levels of tractor weight were used including the static weight (19750 kg) and 2120 kg added weight (tractor weight). Tillage depth treatment included 7.62 cm and 12.7 cm, respectively, and the engine power was controlled at two levels of 100% engine power usage and 70% engine power usage as determined by the transmission gear selection. Each treatment was a unique possible combination of each level of the four factors. The data were analyzed using SAS version 9.4.

## 3.6 Results and Discussion

Figures 3.9 to 3.11 show the descriptive statistics of the results of fuel consumption rate, slippage percentage, and effective field capacity (ha/h).

### 3.6.1 Fuel Consumption Rate

The fuel consumption of the tractor was determined for standard weight and added weight in relation to engine power, tillage depth, and tire inflation pressure. The results are shown in Figure 3.6. The results show there was a significant difference in fuel rate ($P<0.05$) due to engine power, tillage depth, tire inflation pressure, and a significant interaction between tillage depth and engine power. After adjusting for multiple comparison, there was no significant difference ($P<0.05$) between depth 7.62 and 12.7 cm (86.21 L/h and 87.05 L/h respectively) on maximum power. In contrast, there was a significant difference observed at low power for depth 7.62 and 12.7 cm (Figure 3.6).

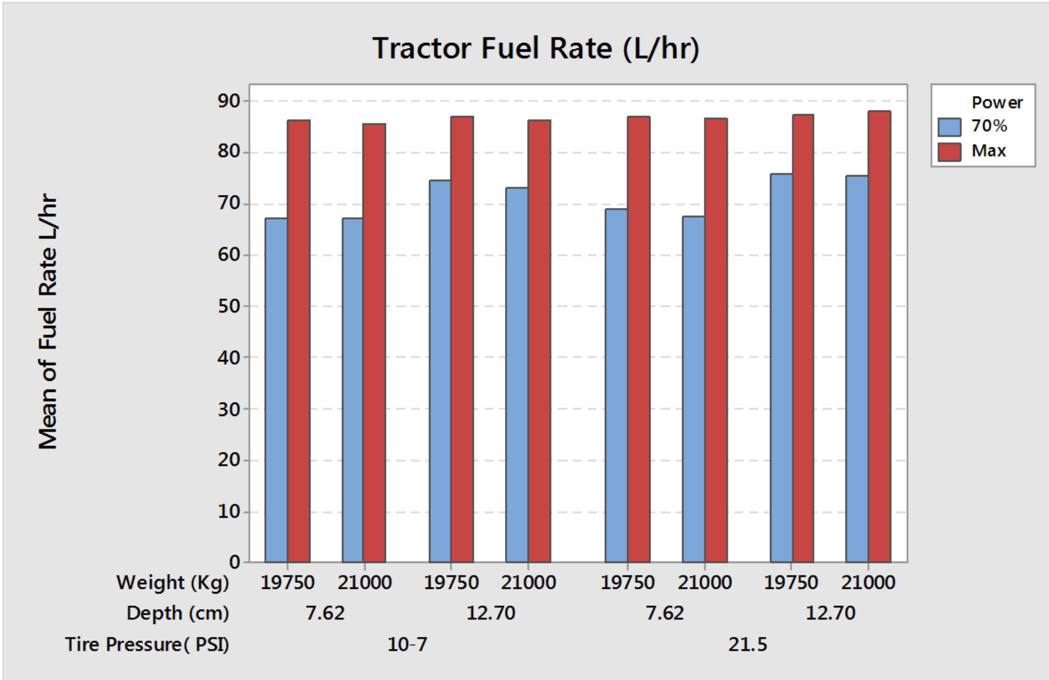



Figure 3.6. Mean fuel rate of tractor with standard and added weight.

Additionally, a significant difference within depth was observed between maximum and 70% power. For instance, at depth 7.62 cm, the fuel rate for the maximum power was 86.21 L/h while 70% power was 67.58 L/h. Increasing tillage depth associated with increasing soil disturbed volume leads to increase tractor load and fuel consumption to pull the implement (Filipović et al., 2004; Moitzi et al., 2006).

In addition, at the standard weight, the maximum fuel consumption (87.24 L/h) was observed at maximum power at maximum depth (12.7 cm) and maximum tire pressure. Likewise, for the same weight, low fuel consumption (67.04 L/h) was observed at 70% power in low depth (7.62 cm) at low tire inflation pressure. Moreover, in adding weight the maximum fuel rate was observed at maximum power and higher depth (12.7 cm) at high tire inflation pressure. Low fuel consumption was observed at low power in low depth (7.62 cm) and low tire inflation pressure (Figure 3.6).

### 3.6.2 Slippage Percentage

The slippage percentage is the key indicator of efficiency of tractor operation. It is used to indicate whether the right combination of tire inflation pressure, overall tractor weight, and operating speed result in optimal fuel usage. The results show the slippage percentage ranges from 8.59% to 24.24%. The high slippage percentage (24.24%) in standard weight was observed at a maximum tire inflation pressure at high tillage depth (12.7 cm) and 70% power. The result also shows that the engine power usage does not significantly affect fuel rate consumption. Additionally, the higher slippage percentage occurred at lower power usage and higher tillage depth. Moreover, for the added weight, the highest slippage percentage (19.80%) was observed at maximum tire inflation pressure, higher depth (12.7 cm) and low power (70%). The lowest slippage percentage was observed at low tire pressure, low tillage depth, and 70% power usage (Figure 3.7). According to Raheman et al. (2007), the optimal slippage percentage lies between 8% and 15%. Increasing the tillage depth from shallow to deep increases the slip percent for low engine power and maximum engine power by 46% and 71% due to the increases in load of extra soil disturbed volume (Al-Ani et al., 2005).

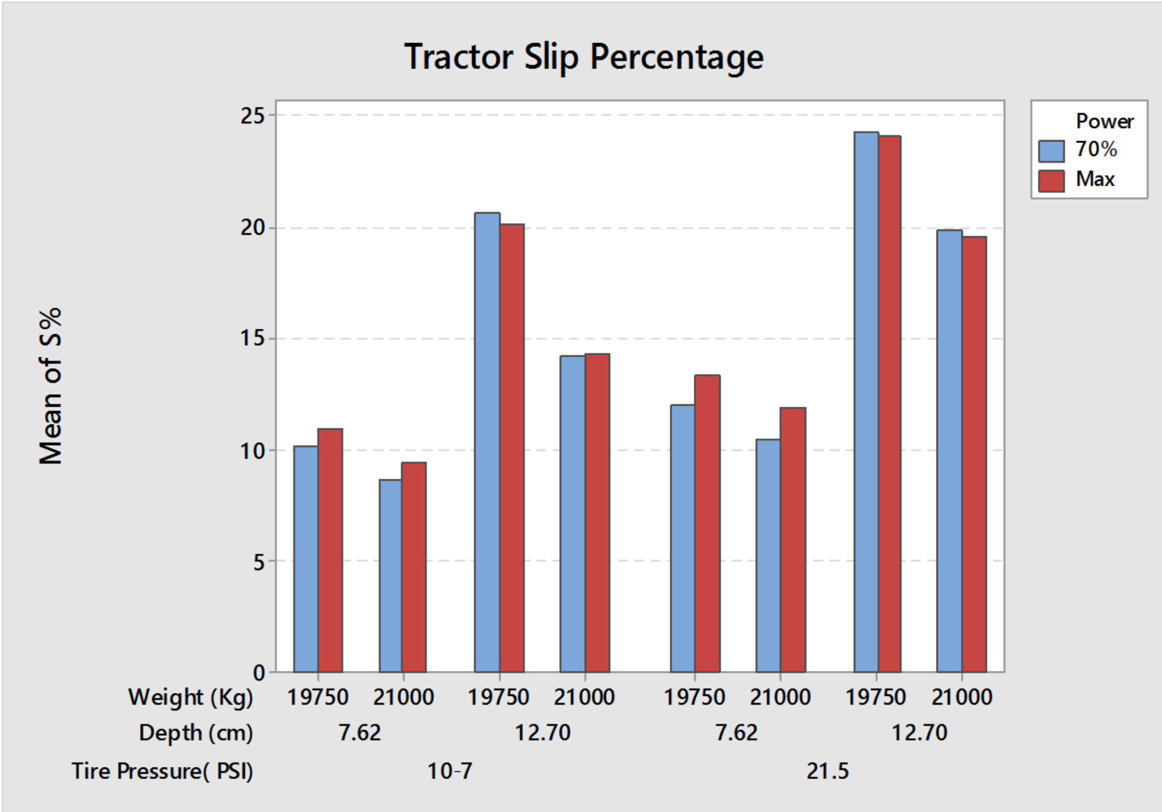



Figure 3.7. Mean slippage percentage of tractor with standard and added weight.

### 3.6.3 Effective Field Capacity

Effective field capacity is the actual productivity of a field machine. It takes into account field efficiency, field speed, and the effective working width of an implement (Roberson, 2008). Figure 3.8 shows descriptive values of effective field capacity. Significant differences were observed in weight (standard and added), tire inflation pressure (low and high), tillage depth (7.62 and 12.7 cm), and engine usage power (70% and 100%). Also, a significant difference was observed in the interaction between depth and engine usage power (depth * power). The effective field capacity for the standard weight ranges from 5.83 ha/ h to 10.47 ha/h. On the other hand, the effective field capacity for added weight was between 6.18 ha/h and 10.82 ha/h. Overall, the highest effective field capacity (10.82 ha/h) was observed at added weight, low tire inflation pressure, shallow tillage depth (7.62 cm), and maximum engine usage power. Likewise, the lowest effective field capacity was observed in standard weight, higher tire inflation pressure, deep tillage depth, and 70% engine power usage (Figure 3.8).

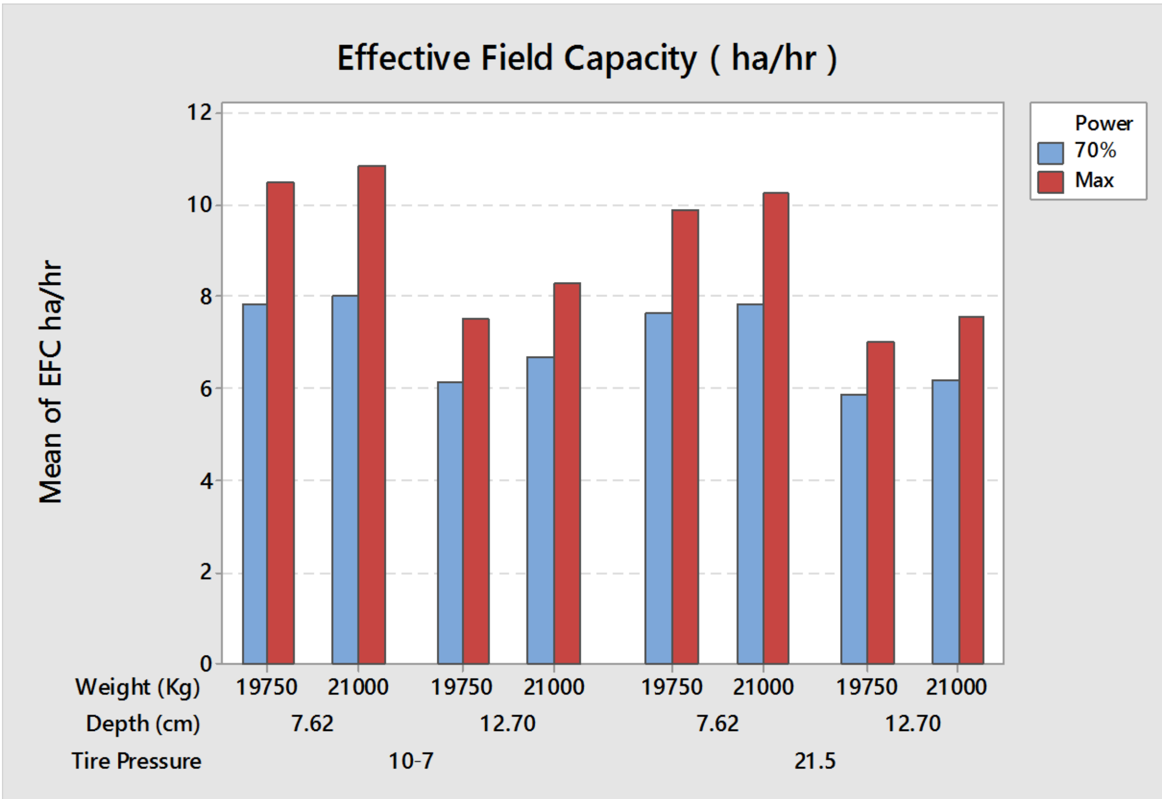



Figure 3.8. Mean effective field capacity of tractor with standard and added weight.

### 3.7 Conclusions

Field performance parameters are used to monitor agricultural machinery performance. A technique like CAN Bus enables operators to monitor agricultural machinery such as tractors in field operations. In this study, CAN Bus was used to collect data and measure the tractor implement performance parameters such as fuel rate, wheel based speed, and GPS speed. The use of CAN Bus technology indicates reliable future use to improve and evaluate agricultural machinery. Changing input variables impact performance parameters. The input variables examined were total tractor weight, tire inflation pressure, tillage depth, and engine power usage. There was no significant difference between standard weight and added in many parameters assessed. The study shows the minimum fuel consumption rate and wheel slip percentage with the utmost field efficiency occurred with a tractor-implement at 70% engine usage power for either low or high tillage depth and at an optimum tire inflation pressure when extra weight was added. Thus, operators need to choose a proper set up to achieve optimum performance and correct decisions for best agricultural management.

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# CHAPTER 4. DESIGN AND VALIDATION OF AN ELECTRONIC DATA LOGGING SYSTEMS (CAN BUS) FOR MONITORING MACHINERY PERFORMANCE AND MANAGEMENT- PLANTING APPLICATION

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## 4.1 Abstract

Present-day agriculture faces major challenges regarding the significant increase in world population and the need to cultivate more land, regardless of their topography, and manage water resources. These issues impose major constraints on agricultural production, and different combinations of these factors may contribute to reducing crop yield production. Present and future agriculture undoubtedly has a vital need to overcome these obstacles to increase food production and meet the needs of a growing world population. A solution to these problems seems to be in the use of electronic systems in agricultural sectors as a practical way to track the performance and efficiency of agricultural machinery units on a real-time basis on flat, uphill, and downhill lands. A controller area network (CAN) binary unit system (Bus) protocol is one such system, and it provides agricultural industries with a unique and powerful technology. This instrumentation technique can provide a significantly more efficient approach to farming systems control and monitoring. In this study, a CAN Bus system was utilized as a user-friendly tool to optimize a high speed John Deere field planter in various

properties of the terrain in order to gain more accurate, real-time information about its performance. This comprehensive method interprets and analyzes several performance parameters of agricultural machinery on a continuous basis. As such, it is an alternative approach to traditional methods of measuring the performance of agricultural mechanization. In this study, CAN data were collected to evaluate the performance analysis of fuel consumption, unit speed, and engine load based upon different tractor-planter configurations on both flat and sloping land. A combination of tractor-planter units was operated in three different fields with three different ground speeds on a wide slope land range. The tractor speeds were 8, 10, and 12 km/hr while sloped angles ranged from -5 to +5 degree. Based upon different tractor-planter configurations on flat and sloping terrains, the analyses demonstrated that both ground speed and slope angle have significant effects on the studied parameters. The findings indicated that an increase in unit speed was associated with increased levels of fuel rate. Also, the results showed that engine percent load was generally lowest for declining terrain, whereas the values of engine percent load were highest for inclining terrain. This unique and powerful technology enables users to make better decisions and maximize mechanization performance for different agricultural operations and various ground surface conditions. When compared to traditional methods of measuring of agricultural mechanization, CAN Bus technologies provide real-time monitoring and safer, more reliable measurements results. This is a concrete demonstration of the practical advancements of CAN Bus which provided key machine performance indicators operating on absolutely flat and sloped fields. This protocol, which is standard for communications technology dedicated to farm machinery, enables users to make better decisions and maximize mechanization performance for different agricultural operations and various ground surface conditions.

## 4.2 Introduction

During the past several decades, the agricultural sector has faced great challenges while increasing food production to meet the growing world population. The most significant challenges are the need to cultivate more land and more efficiently manage water resources. These are the most important elements that are considered as major constraints on agricultural production. These factors alone, and their combinations, contribute to reducing crop yield production (Loevinsohn et al., 2012). Present and future agriculture undoubtedly have a vital need to overcome these obstacles to increase food production and to meet the demands for food and energy (Furbank et al., 2009). A solution to these problems might be a changing agricultural production paradigm that is essential to transition towards increased agriculture production. Today's agriculture production is being improved and has been greatly changed over the last 50 years. The evolution of agricultural production systems in response to mis-management of agricultural machinery led to essential and successful improvement in farming conditions, causing more efficient, highly productive food and fiber production (Huang et al., 1994).

This evolution of agricultural production systems created the advent of agricultural technology, mechanization, automation, and data management that contributed to fundamental improvement in the agricultural production sector to meet the increased pressure of the growing global food demand. These advancements enhance modern developments in processing and transport of agricultural products and also have an impact on the operations in farm technology (Van den Berg et al., 2007; Challa, 2014).

Over the years, there have been many dramatic changes in agricultural systems and applications to expand the lands and increase crop production to ensure food security for the increasing population. To overcome these challenges, there have been many advancements in agricultural systems and applications such as mechanization, automation, and data management to support agriculture. These advancements enhance modern developments in processing and transport of agricultural products and also have an impact on the operations in farm technology (Jakasania et al., 2018). The adoption of electronics in the agricultural field operation improves sustainable agriculture and optimizes inputs. These more effective technologies, such as data management systems, global position system, and robotic, enhance productivity, quality, and crop yield (Jain et al., 2009; Darr, 2012). Currently, the farm industry includes many useful tools for serving farm production. Going forward with sustainable agriculture, the application of CAN Bus modern technology, is crucial. The remarkable success of the use of this technology will determine the performance of agricultural machinery, improve crop yield, and farm productivity (Darr, 2012). The creation of this significant advancement technology provides a unique opportunity to farmers and managers to interact and attain optimal efficiencies and data being collected during field operations (Jakasania et al., 2018).

As farmers experience pressure to improve yield per acre, it is essential for the agriculture industry to adopt innovative technologies during the planting process that optimize inputs, contribute to sustainable agriculture, and improve crop quality (Challa, 2014). Since 1985, the innovation of planters in the United States has contributed to positive and continuous improvements to seed operations by increasing the crop productivity and making the planting operation more efficient. Seeding or planting operations in agriculture are the most important and critical period processes follow tillage land preparation. Crop productivity is greatly influenced by optimum plant populations, appropriate timing, and planting according to specific characteristics, such as spacing and amount per area, for satisfactory emergence and better germination. Using electronic systems can be used to evaluate the performance of a specific farming system such as tillage, planting, and harvesting (Kariyasa et al., 2011; Jain et al., 2009; Leen et al., 2002).

Recently, the applicability and suitability of many agricultural operations and practices require farmers to access more accurate information on a real-time basis to monitor, control, analyze, and calibrate machine performance of tractors and planters such as engine speed, practical speed, fuel consumption, and engine percent load. Thus, the overall purpose of this study is to quantify the effects of performance data for tractor-planter serves as the backbone and has an essential role in improving farming activities effortlessly. The work reported in this research consists of the following objectives:

A. Develop, evaluate, and validate the adoption of Controller Area Network (CAN) binary unit system (Bus) software in measuring the performance of planting operation such as engine speed, tractor practical speed, fuel rate, and engine percent load.
B. Determine the effect of slope angle and ground speed on fuel rate and engine percent load.
C. Provide recommendations about utilizing this CAN Bus protocol to maximize the efficiencies of fuel consumption and engine percent load for agricultural machinery used in this experiment.

## 4.3 Literature Review

In the 1960's, the farming industries began implementing and capitalizing on gaining the benefit of the application of electronic control units (ECU) and sensors within the field of the agricultural (Stone et al., 2008).

In 1986, Robert Bosch GmbH worked together with Mercedes Benz Inc. to develop a Controller Area Network (CAN) binary unit system (Bus) application, which allowed three automotive microcontrollers applications to intercommunicate (Voss, 2008). Since then, CAN Bus systems have been identified as a major contributing factor for agricultural operations and have significantly improved the operational performance of agricultural machines and yield monitors (Darr, 2012). CAN network has been extensively utilized as industrial-automation, and real-time communication approach at lower cost due to replacing the complicity of connectors and wiring harnesses. Furthermore, CAN network enabled point to point communication of thousands of signals between machine electronic circuit units (ECUs), reduced noise interference, and improved data collection which ultimately helped users easily monitor machine performance (S. K. Pitla et al., 2014; Trostle, 2008).

The distinct benefits of CAN protocol stimulates industry areas to adopt it for popular building automation, medical applications, marine, military, and agricultural practices. This successful data acquisition system has dramatically enhanced worksite management practices, strategies, and decisions. A considerable amount of literature in the field of agricultural mechanization has been published on the instrumentation of electronic technology and field measurement performance (Darr, 2012b; Grisso et al., 2004). These studies focused on how monitoring and controlling agricultural machinery functions have empowered applicants to make better decisions. As a prime example, Darr (2007) utilized such a system which digitized and monitored an animal building facility to improve air quality for better environment. In another major study, Al-Janobi et al. (1997) and Al-Suhaibani et al., (1997) developed an instrumentation system to determine engine rpm, fuel temperature, drawbar pull, fuel consumption, axle torque, and weight for a tractor in an effort to help farmers and owners to direct assessment and documented machines' functionality. Furthermore, Sumner (1986) found that using electronic systems in agricultural sectors was a practical way to track the performance and efficiency of agricultural machinery units on a real-time basis.

Additionally, Bedri used a single microcomputer chip to identify fuel consumption, speed and slip percentage of a tractor-implement unit with high accuracy (Bedri, 1981).

There are a variety of proprietary solutions (e.g., sustainable agriculture, precision agriculture, information management, yield monitoring, and instruments and measurement techniques) that can be used to increase the mechanization of farming practices and food production for more profitable existing and future farming activities. For example, Yahya et al. (2009) conducted a similar study under field conditions. In this study, the logging device which was utilized gathered key machine information for a tillage unit. Grevis-James et al. (1983) designed a computer-based device as a yield mapping system to monitor tractor performance. This system was capable of extracting performance data for a tractor- implement unit.

Agricultural mechanization and farming practices have been pioneered and used to automatically monitor various farm activities (e.g., plant protection, livestock production, green house practices, and agricultural mechanization). Wei et al. (2001) performed a similar series of experiments in 2001 to detect weeds and apply herbicides by designing a CAN network that gathered and transmitted required data in real time. This study helped to empower and strengthened agricultural productivity. Hodge discussed the potential of using empirical models of data acquisition systems in a field study to improve agricultural productivity (Hodges, 1982). Al-Janobi et al. (1997) utilized a logging device to obtain reliable machine data during a field test. In their study, a data logging instrument produced a data stream for monitoring different operational parameters. Data from instantaneous machine operation were recorded such as torque and forces acting on the tractor wheel.

Al-Suhaibani et al. (1997) captured different direct measurements of machinery field performance parameters by accessing controller-area-network (CAN). This approach allowed them to obtain accurate value for the data collection system by extracting data (i.e., drawbar pull, ground speed, and drive wheel speed) during machine operation hours.

The major purpose of data logging systems and sensors in agricultural field machinery was to collect and validate data. This approach enabled Kortenbruck et al. (2017) to create a system user interface which is capable of generating data collection commands. This system was able to capture data live, calculate and evaluate key machine information, and automatically analyze collected information instantaneously. The instrumentation system was capable of measuring and predicting the performance of mechanization practices. This in turn, was essential for taking precise decisions.

Deutsch (2016) performed a similar series of experiments to show the applicability and suitability of using massive amounts of data to understand and predict agricultural machinery tasks. He found that serial communication necessitates operability, ease of use, and more efficient data processing in real time. He developed a data acquisition system to determine performance parameters of agricultural unit in the field test.

An instrumentation system was designed exclusively to determine various performance parameters of an agricultural machinery unit (Scarlett, 1993). Grisso et. al. (2008) extracted and evaluated output data for various field operations such as combine and planter in soybean and corn yield production. This feasible approach had the capability of quick measurement of various functionalities of the unit.

Agricultural modernization in the ongoing massive amount of data transfer between agricultural mechanization these days is well recognized. The massive collected data represents hours and days of field work. In order to ensure compatible and reliable data transmission, numerous data collection platforms were developed. The development of data collection platforms led to solving more complex agricultural tasks which yielded better outcomes (Clark et al., 1985; McLaughlin et al., 1993). It became apparent that the evolution and merits of technological advancements in the agricultural machinery industry opened a new door for more analytical techniques. With these sophisticated integrations, the direct measurements, visualizing, and documentation of instant agricultural vehicles performance metrics became easier to access. The crews were tasked to gather information (Molari et al., 2012; Molari et al., 2013; Pitla et al., 2016).

Advances in technology have been spreading rapidly among farming operation and for different agricultural tasks throughout the world. The rapid growth in demand for meat products must keep pace with food security issues. Darr et al. (2007) performed a formidable task by applying microcontroller technology to livestock and poultry industries. His findings demonstrated that laboratory and field tests can sense and record environmental parameters of animal housing by embedded sensors.

### 4.3.1 Working on Sloped Land

Primitive agriculture was only capable of using flat land due to limitations on how to use other various types of land. Over time, producers developed various farming methods in order to utilize a wide variety of land conditions in order to meet the demands of an ever-growing global population. By 2050, cropland area and agriculture production will need to increase by 70% (Furbank et al., 2009). To achieve this increase in crop production demand for agricultural commodities to feed both people and livestock, producers need to use all farmland available in higher efficiency for all topography. Power machinery and their efficiency varies when agricultural machinery operates on sloped land compared to flat land (Jarasiunas, 2016; Mackney et al., 1968). Agriculture on slope farmland is challenging for farmland operations and practices, affecting productivity and income.

### 4.3.2 Sloped Land: Definition and Measurement Techniques

In simplest terms, slope is change in height (vertical) distance over a horizontal distance. This simple formula is often expressed as ‘rise over run.”  Multiplying this value by 100 will convert it to percentage (Figure 4.1).

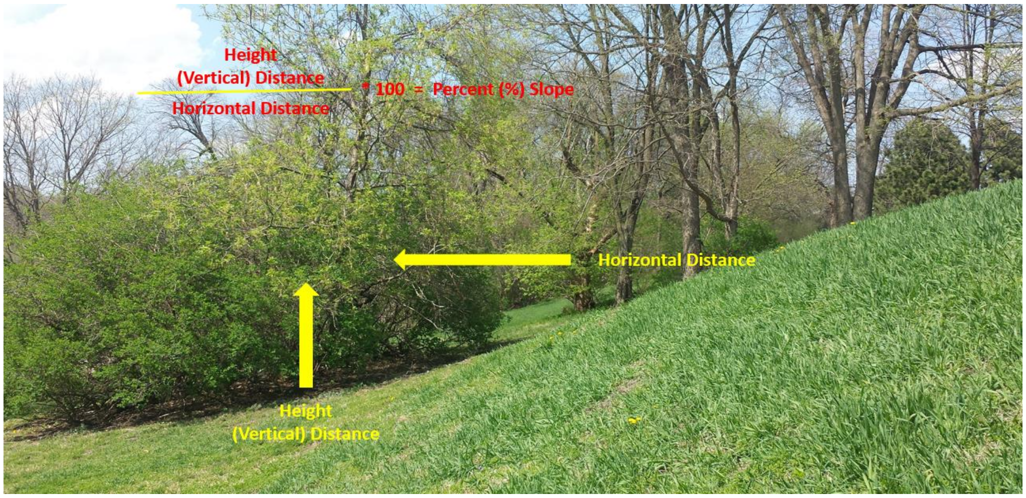


Figure 4.1. Calculating slope percent.

Slopes of 6% or less are of relatively little concern. A quick and basic method to estimate whether slope is more or less than 6% can be done by two adults facing one another 100 feet apart. One of them can use any flat surface to block the horizontal site line below. If the person on the uphill side can see any part of the downhill person's body, then the slope is most likely less than 6% (Figure 4.2).

Figure 4.2. Field method to determine slope.

More precise measurement is required if the sloped land is greater than 6%. The simplest way to determine this is by using a carpenter level, a 50-inch board, and a tape measure. The procedure starts with placing the board on the representative ground location with the board length following the downward slope being measured (Figure 4.3). Then the level is set on the board, and the lower end of the board is lifted up until it is completely horizontal.  A vertical measurement is obtained by measuring the distance between the board and ground level.

Figure 4.3. Slope measurement settings.

Figure 4.4. Measuring slope on the field.

Then the level is set on the board, and the lower end of the board is lifted up until it is completely horizontal.  A vertical measurement is obtained by measuring the distance between the board and ground level.

To determine the slope, the vertical distance is divided by the length of the board and then multiplied it by 100 to express this value as a percentage  (Figure 4.3). To ensure the most accurate measurement of the slope of all areas, several measurements should be taken at different spots to calculate the average percent slope.

Usually when wheeled agricultural machines operate on uneven terrain, slope is a factor that can affect the performance indicators such as field efficiency and machine capacity (Khot et al., 2008; Laughery et al., 1990; Owen, 1981; Tarokh et al., 2013). To gain a better understanding of the static and dynamic behavior of machinery on sloped fields, it is crucial to determine each type of forces that interact with the terrain. This can enhance producer's ability to make informed decisions when performing different agricultural operation tasks.

### 4.3.3 Tractor (Body Frame) Rotation Angles

Ideally, agricultural vehicles correspond reasonably well with the ground surface positions and topography. In addition to creating the Sigma symbol (Σ) for summation and e numbers (e=2.71828), Leonard Euler (1707-1783) posited that three successive rotations, called Euler angles, are necessary to describe a general orientation of a rigid body: roll angle (RA), pitch angle (PA), and yaw angle (YA).  These angles can be seen in Figure 4.5.

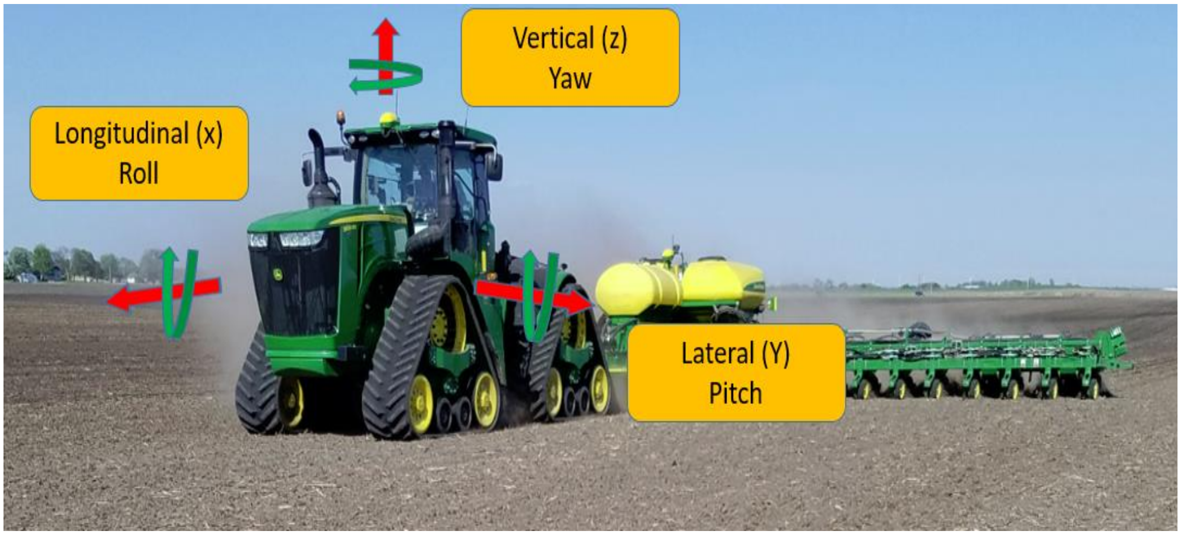


Figure 4.5. Simple example of tractor rotation around X, Y, and Z leads to rolling, pitching, yawing overturn, respectively.

Euler angles can be used to describe different orientations of vehicle axes and their combinations. In a rolling angle a rover vehicle will use left-right type of movements, which is also known as side-slope angle. In terms of pitch angle, the vehicle will move in an uphill or downhill direction, which will affect the center of gravity. A yaw angle emerges when agricultural vehicle rotates on a vertical plane. This order of the components of Euler angle (e.g., RA, PA, YA) can be used differently in different applications. These angles can be used to describe the orientation of the vehicles about different axes and their combinations. For example, in a rolling angle a rover vehicle will use left-right type of movements which is also known as side-slope angle. In terms of pitch angle, the vehicle will move in an uphill or downhill direction; it is important to note that this movement will effect the center of gravity. A yaw angle emergence when agricultural vehicle rotates from a vertical plane. These terrain properties and Euler angles phenomenon can be determined with high accuracy using inertial measurements units (IMU) typically embedded within GPS navigation systems.

### 4.3.4 Crawler Type Tractor

The idea of crawler tractor equipped with steel tracks instead of wheels has been around for a long time and was tried by different inventors during the 1800's. In 1900, Alvin Lombart designed what became known as the Lombard log hauler, which was a steam tractor. In 1906, Benjamin Holt in California designed a rigid crawler for a gasoline powered engine which operated in the California delta. In 1908, the Caterpillar Incorporation was born by these two companies merging to produce tractors for all types of conditions and all-terrain vehicles (ATV). These steel metal models were generally operated on uphill and downhill with as much of 60% grade, mud, and water.


Figure 4.6. Basic crawler tractor.

Typically, the main idea of rigid tracks is to distribute the weight of the tractor to enlarge contact area to reduce the amount of pressure on the ground and to increase traction on soft, loose soil surfaces, gaining more powerful traction ("www.caterpillar.com,"). Thus, increasing ground contact area results in more power being transmitted to the drawbar than for wheeled tractors (Culshaw, 1988; Keen et al., 2013). These steel crawler tracks, which are primarily for traction, are being used in construction and agriculture. These track tractor systems are still popular in some countries and utilized in large scale farms and soil conditions (Bashford et al., 1999; Okada, 1966). The basic application of crawler tractors was originally in mountainous areas, areas where swamps are abundant, areas of land reclamation in settlement processes, the installation of bridges, and the construction of channels. Despite the advantages of track, steel tracks have high maintenance cost, low travel speed, restriction to surfaces, and low maneuverability.

In the early 1990s, Caterpillar introduced a new Challenger series design for row crop and tillage operations featuring rubber track driven by the rear wheels (Figure 4.7).


Figure 4.7. Crawler tractor, CAT Challenger model 75E with rubber belted tracks. (Caterpillar, Inc.).

30 years ago, a Rubber-tracked systems have become available on self-propelled and heavy agricultural vehicles. This is due to the fact that rubber crawler tractors combine advantages over both pneumatic and metal-tracked tractors. Compared to four wheel drive

(4WD), rubber-tracked tractors generate higher tractive efficiencies with less slippage, net and gross traction, better floatation, and less compaction. However, when compared to steel track tractor, rubber track tractors have reduced maintenance cost, improved maneuverability, higher travel speed, and ability to travel on paved and other roads surfaces (Esch et al., 1990; Zoz, 1997).

The adoption of the quad rubber-track tractors (i.e., four tracks replacing wheels; Figure 4.8 was introduced in 1987 by Caterpillar incorporation with the mobility advantages of a 4wd tractor (Evans et al., 1986).

The robust design of this tractor uses a positive drive undercarriage system to effectively transfer engine power to maintain traction while turning under load with optimal weight distribution (Arvidsson et al., 2011; Bashford et al., 1999).

Figure 4.8. Quad rubber-track tractor used in the experiment.

The quad rubber-track tractor became commonly used in off-road vehicles, agricultural (e.g., tractors, combines, etc.), construction, and military vehicle applications. Like two track vehicle, quad rubber-track tractors provides advantages such as greater flotation, reduced compaction, continuous footprint for better traction less slippage, more evenly distribute weight, simplified transport, minimized ground pressure, and better maneuverability on uneven ground.

## 4.4 Materials and Methods

The objective of this study was to understand the impact of terrain variation on agricultural vehicle performance and to optimize decision making. This information will help operators make a sequence of quick decisions to optimize seed operations. To achieve such optimization, we conducted a study where three tractor speeds, 8.0, 10 and 12 km/hr (4.7, 6.7, and 10 mph) were selected, tractor engine speed was maintained constant to correspond to each treatment, and a one-second sampling interval was extracted.

### 4.4.1 Experimental Fields

The experimental work focused on evaluating the performance of a tractor-planter combination unit. This study was conducted in an agricultural field at the Biocentury Research Farm (BCRF) in Ames, Iowa, USA. The aim of the evaluation was to measure the direct and indirect parameters of the unit on different topography. Four distinct fields at the BCRF were chosen for this experiment, as each field presented different topography features. Two of the fields produced corn and two fields produced soybeans in the previous growing season.

Figure 4.9. Field topography, front view (West Bisland).

Figure 4.10. Field topography, side view (West Bisland).

Figure 4.11. Field topography, back view (West Bisland).

### 4.4.2 Instrumentation

A quad tractor (9520RX John Deere) with 30 inch wide, triangle rubber tracks was equipped with a 1770NT CCS24Row30 John Deere corn planter and used to test the effect of speed and sloped terrain variation on physical measurements such as fuel consumption, engine torque, and engine load (Figure 4.12).

Figure 4.12. John Deere tractor with a 24 Row corn planter.

Several key technical specifications of the tractor are shown in Table 4.1, and several key technical specifications of the planter are shown in Table 4.2 (John Deere tractors, Moline, USA).

Table 4.1 Tractor specifications.

| |
|---|
| **Engine:** |
| MODEL 9520RX |
| Rated engine power: 520 hp (382 kw) |
| **Transmission:** |
| e18 Transmission, 18 F/6 R Speeds with Efficiency Manager |
| **Tracks** |
| 762 mm (30 In.) Width, Camoplast DURADRIVE 3500 Tracks |
| **Tractor weight** |
| 24200 kg (5250 lb) |

Table 4.2 Planter specifications.

| |
|---|
| Model : JD 1770NT PLANTER, 24 ROW 30, |
| Rows : 24 |
| Row spacing : 30in |
| Metering system : vacuum |
| Frame : Flex Fold |
| Implement weights: 15000 lb |

A CAN data logger instrument (Vector GL 1000 (8910)) was utilized to record and store all J1939 standard messages from the physical measurements that are available on the Bus. This logging device has been used extensively by many researchers at Iowa State University to record data of multiple machines parameters (Bashford et al., 1999; Covington, 2013; Peyton, 2012; Powell, 2014). The onboard data acquisition system recorded the output from the original equipment manufacturer (OEM) sensors. No additional sensors were instrumented on either piece of equipment (Figure 4.13).

### 4.4.3 Data Collection and Handling

The CAN logger recorded and stored all the messages produced by the test tractor and planter for the entire test period as input data over a speed range. A laptop was attached through Universal Serial Bus (USB) to the ISO tractor diagnostic ports to interface the logs. (Figure 4.13). Figure 4.14. Screenshot of the CAN message data captured using the Vector CAN software for is a screenshot of the CAN message data captured using the Vector CAN software for PGN (0xFEF2 = 65266) for engine fuel rate (06CC= 1740*.05 = 87 l/hr) obtained during the test.


Figure 4.13. CAN data logger and USB.

SAE J1939 standards was utilized to meet the requirement of collected data and to specify the desired PGN based on the signals embedded in the particular message. These operational CAN data were recorded and numbered consecutively (Table 4.3).

```
103.028971 1  18FEF200x Rx d 8 CC 06 FF FF FF FF FF FF
```

Figure 4.14. Screenshot of the CAN message data captured using the Vector CAN software for PGN 0xFEF2 = 65266 for engine fuel rate (06CC= 1740*.05 = 87).

Table 4.3 Description and source of captured machine parameters.

| Data | PGN | Length (Bits) | Unit |
|---|---|---|---|
| Latitude | 65267 | 4 bytes | degree |
| Longitude | 65267 | 4 bytes | degree |
| Engine speed | 61444 | 8 | Rpm |
| Engine load | 61444 | 8 | % |
| Engine torque | 61444 | 8 | % |
| Fuel rate | 65266 | 8 | l/hr |

The data transmission rate, or baud rate affected by time between two consecutive messages, was configured independently for each Bus. The baud rate for the tractor bus, bus1, was set to 500 kbit/s. The ISO bus, bus2, baud rate was set to 250 kbit/s. Another two more buses, bus3 and bus4, were utilized to receive speed messages from both motors on the left and right sides planter unit, respectively (Figure 4.15).

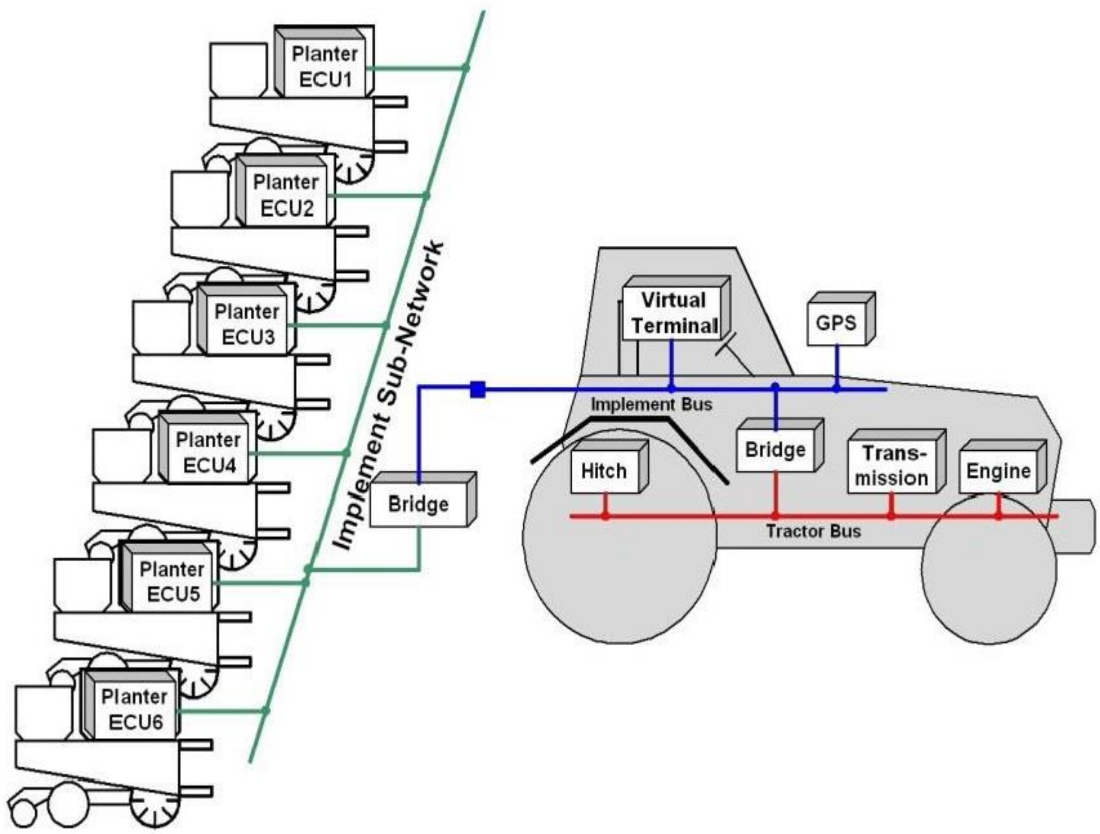


Figure 4.15. Multiple networks on an agricultural tractor and implement buses (Darr, 2012).

In the basic configuration, both standard and proprietary messages were recorded and coded as American Standard Code for Information Interchange (ASCII) file in a one-second, time stamp, and arrangement. Data were recorded as hexadecimal (Hex) values, as shown in (Figure 4.16). These files were converted by J1939 standard messages into engineering values.

| ts_sec | ts_usec | channel | mid | pgn | sa | dlc | d0 | d1 | d2 | d3 | d4 | d5 | d6 | d7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 744 | 992607 | 1 | CFEE8F0 | FEE8 | F0 | 8 | 124 | 116 | 2 | 0 | 71 | 100 | 168 | 88 |

Figure 4.16. Hexadecimal (Hex) values to find a specific PGN (FEE8).

These ASCII files were uploaded to a Structured Query Language (SQL) database server. SQL queries (Appendix 1) were used to select and decode only the data that was relevant to this study based on ISO standard, Parameter Group Number (PGN), tractor speed, and planter parameters. The queries were structured based on the results only if it is within a certain field boundary, to extract the data. The flow chart below shows the process to set up the data acquisition system and the procedure of data processing for the experiment (Figure 4.17).

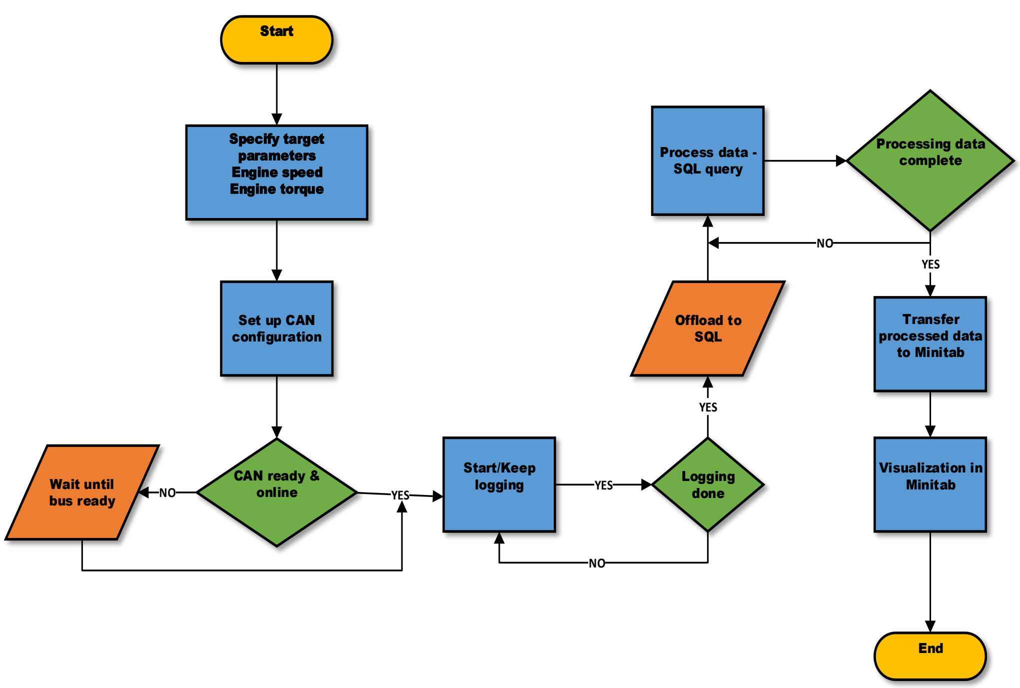


Figure 4.17. Flow chart for data processing.

### 4.4.4 Structured Query Language (SQL)

In general terms, SQL is a standardized language used to access, communicate, and manipulate data in databases. SQL is preferred over a variety of software, especially in sorting and running mathematical operations and equations to transform the hex values to engineering units. In this experiment, specifically, there is a substantial amount of high-speed text data transmitted. As opposed to Matlab and Excel, SQL deals with only the data that is relevant to the query, making the data processing substantially faster. It can also run on parallel processing systems. SQL code was written to measure the Latitude, Longitude, Navigation based speed, GPS speed, Engine torque, and engine percent load.

The *average* function, which is represented by “avg”, is the average value of the numeric values in column of a table. It ignores null values during calculations. A *select* command is the most common statement used in SQL which helps to select a specific column or all columns required from one or more than one tables and retrieve data in the database.

```
(Select ts_sec, AVG((d4*256 + d3)*.125) AS EngSpeedRpm
FROM ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
WHERE ref_id = @ref_id
AND pgn = 'F004'
AND channel = 1
GROUP BY ts_sec, d3, d4
) AS EngSpeedRpm
LEFT JOIN
(Select ts_sec, AVG((d1*256 + d0)*.05) AS FuelRateKmpL
FROM ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
WHERE ref_id = @ref_id
AND pgn = 'FEF2'
AND channel = 1
GROUP BY ts_sec, d0, d1
) AS FuelRateKmpL ON FuelRateKmpL.ts_sec = EngSpeedRpm.ts_sec
```

Figure 4.18. SQL sample code.

Ground speed and row unit seeding motors speed were used for filtering the required data. There are numerous projects and a substantial amount of data on the server, but SQL is able to quickly select a specific data set that is related to the field based on the time of creation, known as ref-id. Each file uploaded to SQL has a ref-id and each ref-id is unique to that one log for one location, which can be found by cross-referencing the metadata table. A metadata table is a text document summarizing basic information to help identify log contents, which improves search engine optimization (SEO). This data model provides search, browse, filter, and locate functions for specific documents on a topic over the files. In other words, the file name contains start time of the logs and it is extremely helpful to describe documents in additional and greater detail. The true file name was found and compared to the date and time that it was created.

A metadata table is a text document summarizing basic information to help identify log contents, which improves search engine optimization (SEO). This data model fundamentally serves to search, browse, filter, and locate functions for specific documents on a topic over the files. In other words, the file name contains start time of the logs and it is extremely helpful to describe documents in additional and greater detail. The true file name was found and compared to the date and time that it was created.

This is an example of SQL’s utility and can explain (By understanding the aspect of SQL, this is almost an example) why other groups or industries want to look at using SQL in very similar activities.

#### 4.4.5 Global Position System (GPS)

GPS data such as latitude, longitude, speed, and pitch angle was recorded using a StarFire 6000 at a frequency of 10 hertz with real time Kinematic (RTK) using a local base station for ground correction (Figure 4.19). This frequency provides an increased level of accuracy (plus or minus 1.2 inches). All the data from the GPS receiver was included in the CAN data logs.

GPS data played a significant role in the analysis of machine parameter activity and functionality as it maps field boundaries. GPS for any specific field, known as GPS coordinate field boundaries, enable SQL filtering to only the desired fields and provides the ability to map the extracted values to the in-field coordinates. High accuracy elevation data and boundaries mapping for the selected field was also converted into topographic maps for the ongoing task and correlated to position. This provides the capability terrain compensation technology to detect tractor angles (pith, roll, and yaw) of the vehicle.


Figure 4.19. Starfire 6000.

## 4.5 Results and Discussions

The influence of field operating conditions on the two performance indicators (i.e., engine fuel rate, engine percent load) were studied. The operating conditions were expressed by the ground speed of the agricultural unit and terrain angle, also referred to as a slope angle or pitch angle, in three different fields. Ground speeds were 8, 10, and 12 km/h and the slope angles ranged from approximately -5 degree to +5. Field tests were recorded and processed for the following three fields located in Ames, Iowa, USA: Been, Creek, and West Bisland. Regression analyses were performed on both fuel rate and engine load.

### 4.5.1 Fuel Rate

Fuel consumption is considered to be one of the most useful indicators for determining optimal tractor performance for agricultural machinery owners and operators. The results of the regression analysis for the three fields showed significant effects for ground speed on engine fuel rate. For the Been field, regression findings indicate that ground speed ($b = 4.216$, $p < 0.01$) was significantly associated with fuel rate. This model accounted for 97% of the variance in fuel rate (model R2 = 0.97). For the Creek field, regression results show that both ground speed ($b = 3.067$, $p < 0.01$) and slope angle ($b = 3.68$, $p < 0.01$) were significantly associated with fuel rate. This model accounted for 98% of the variance in fuel rate. For the West Bisland field, regression results suggest that speed ($b = 3.089$, $p < 0.01$), slope ($b = 1.658$, $p < 0.05$), and the interaction of speed and slope ($b = 0.3236$, $p < 0.01$) were significantly associated with fuel rate. This model accounted for 98% of the variance in fuel rate. In summary, these findings demonstrate that ground speed plays a major role in fuel rate across all three fields, while slope influences fuel rate in the Creek and West Bisland fields. Finally, the significant interaction effect in the West Bisland field indicated that the relationship between speed and fuel rate varies as a function of slope on this particular field.

Table 4.4 Regression results for field-related fuel rate.

| Field | Variable | Beta Coefficient | *P* | $R^2$ |
|---|---|---|---|---|
| Been | | | | |
| | *Constant* | *27.71* | | *0.968* |
| | *Speed* | *4.216* | *0.000* | |
| | *Slope* | *2.220* | *0.240* | |
| | *Speed × Slope* | *0.333* | *0.090* | |
| Creek | | | | |
| | *Constant* | *33.16* | | *0.983* |
| | *Speed* | *3.067* | *0.000* | |
| | *Slope* | *3.680* | *0.0020* | |
| | *Speed × Slope* | *0.1810* | *0.0740* | |
| West Bisland | | | | |
| | *Constant* | *32.88* | | *0.988* |
| | *Speed* | *3.089* | *0.000* | |
| | *Slope* | *1.658* | *0.0140* | |
| | *Speed × Slope* | *0.3236* | *0.000* | |

The following regression equations can be used to predict fuel rate regarding ground speed and slope angle across fields.

Been:

Fuel Rate (L/h) = 27.71 + 4.216 Speed + 2.22 Slope + 0.333 Speed*Slope

$$R^2 = 0.968 \qquad (1)$$

Creek:

Fuel Rate (L/h) = 33.16 + 3.067 Speed + 3.68 Slope + 0.1810 Speed*Slope

$$R^2 = 0.983 \qquad (2)$$

W Bisland:

Fuel Rate (L/h) = 32.88 + 3.089 Speed + 1.658 Slope + 0.3236 Speed*Slope

$$R^2 = 0.988 \qquad (3)$$

Findings suggest that, in general, an increase in speed was associated with increased levels of fuel rate. Figure 4.20 to Figure 4.23 clearly show and represent the three regression equations (1-3), respectively.

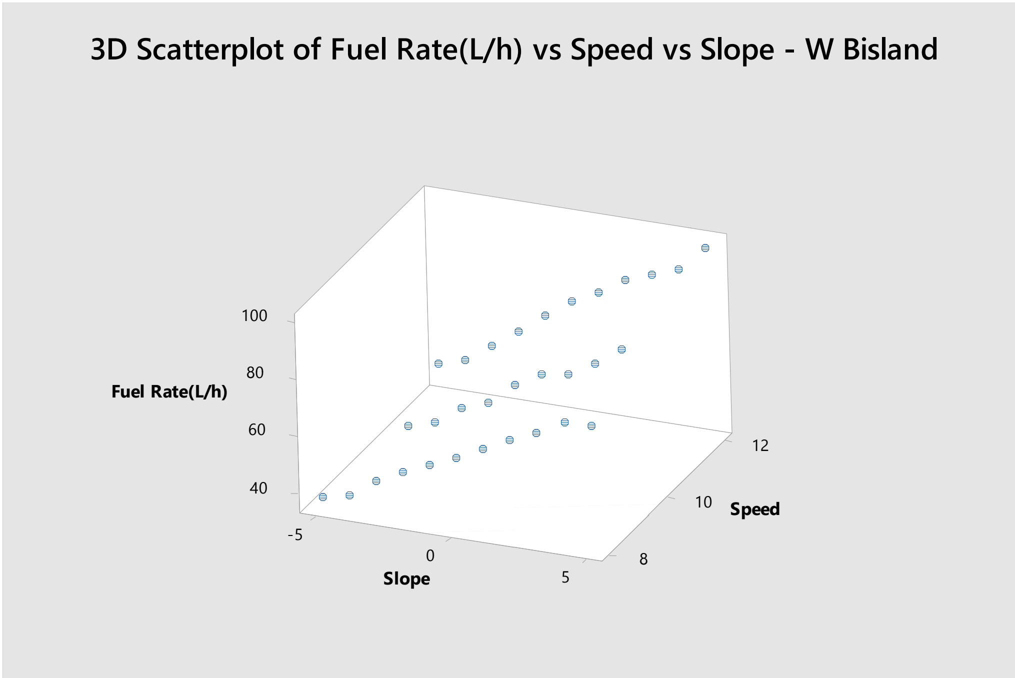


Figure 4.20. The relation between fuel rate, three slopes, and three speeds for the West Bisland field.

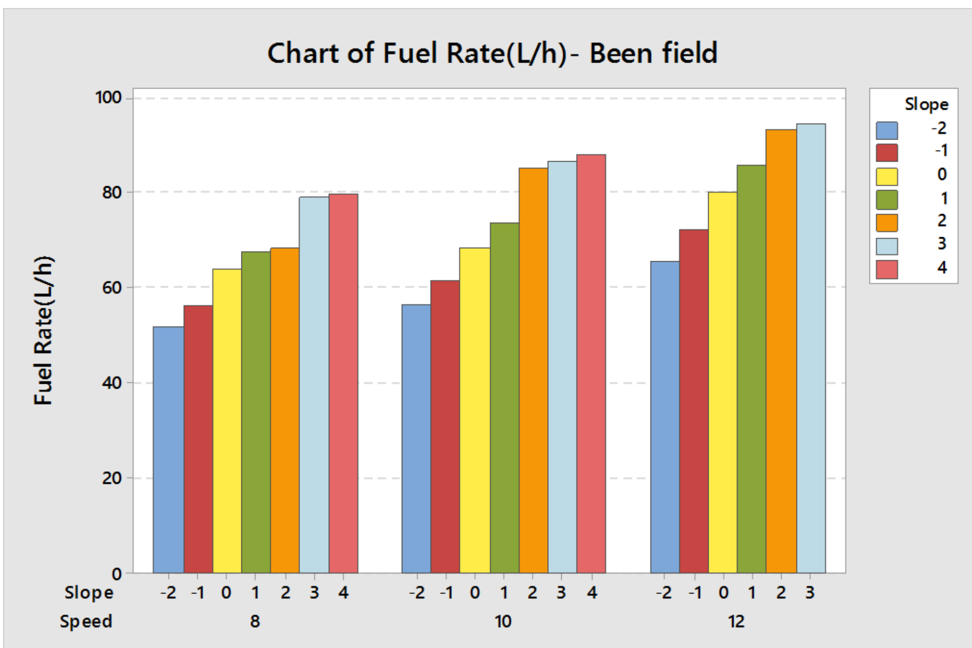


Figure 4.21. The effect of three practical speeds and differing slope on engine fuel rate for the Been field.

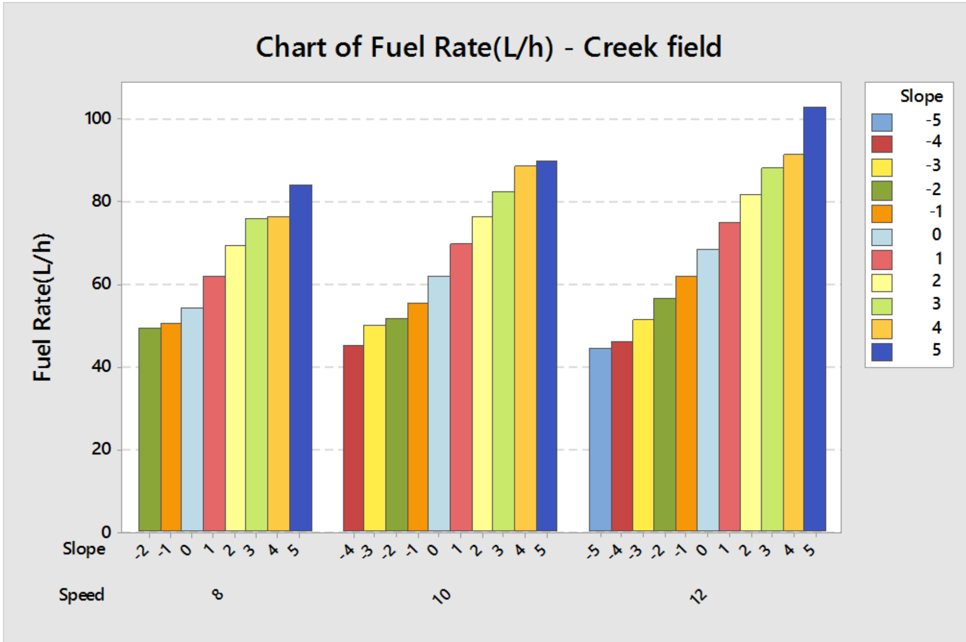


Figure 4.22. The effect of three practical speeds and differing slope on engine fuel rate for the Creek field.

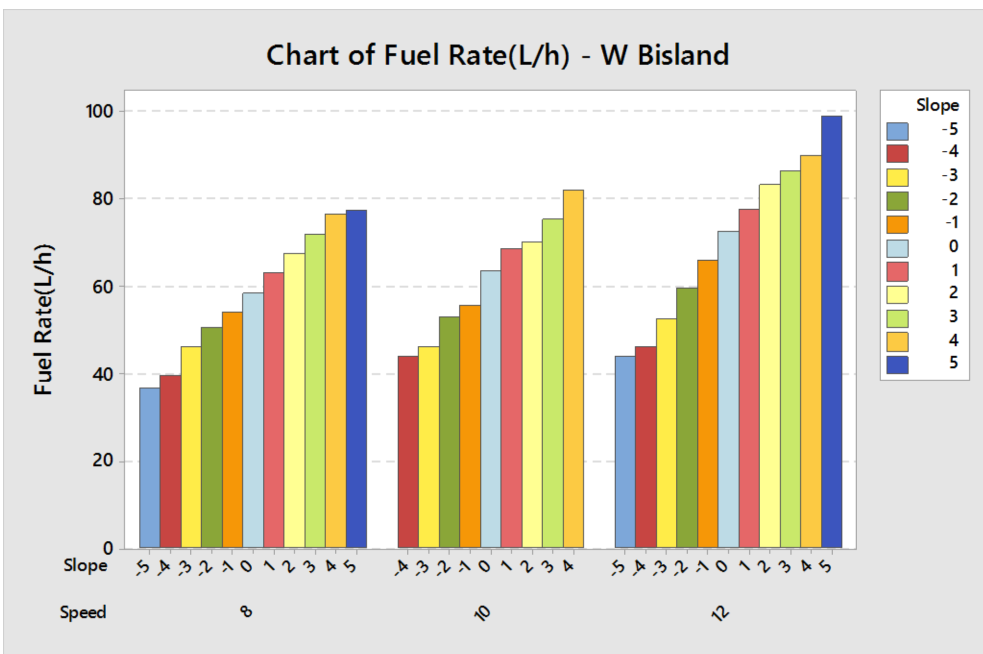


Figure 4.23. The effect of three practical speeds and differing slope on engine fuel rate for the West Bisland field.

In general, the maximum fuel rates were obtained at the highest operating tractor ground speed, whereas, the minimum value of fuel rate was observed at the lowest operating ground speed. For example, an assessment of trends of specific slope type (e.g., zero) across the three tested ground speeds (e.g., 8, 10, and 12 km/h) for the West Bisland field demonstrated that when ground speed was 8 km/h, the fuel rate was about 58 L/h for zero slope angle, with increasing ground speed from 8 to 10 km/h (2 km/h increase) fuel rate increased by about 5 %. As expected, when the tractor ground speed increased from 10 to 12 km/h (a 2 km/h increase), for the same slope angle (zero), the fuel rate increased by 9 % (Figure 4.23). After examining Figure 4.20 through Figure 4.23, it can be seen, for all three fields, that the highest negative slopes yielded the lowest fuel rate across all three ground speeds (8, 10, and 12 km/h).

A close look at Figure 4.20 demonstrates the comparison among the averages of fuel rates and slope angles for different speeds for the West Bisland field. As anticipated, the data demonstrate that lower slope angles experienced a downward trend in fuel rate, while high slope angles showed an upward trend in fuel rate throughout the selected ground speeds for this field. For example, fuel rate was about 37 l/h at ground speed 8 km/h, for the -5 slope angle. For the same speed, when the slope angle gradually changed from -5 to +5, the fuel rate changed from 37 to 77. Total fuel rate was in the range 37 to 99 (l/h) for West Bisland field.

As previously mentioned, the other two fields (i.e., Been and Creek) followed a similar pattern of results regarding the effect of ground speed and slope angle on fuel rate as the West Bisland field.

There is a related study shows the relation between tractor ground speed and engine fuel rate. Bashford et al. (1999) reported some of their results about fuel rate of a tractor. The lowest fuel rate was obtained at the minimum ground speed due to engine speed (rpm). Increasing engine speed means injectors provide more fuel to burn, which means higher consumption of fuel (Bashford et. al, 1999).

### 4.5.2 Engine Load

The data analysis of engine load provided a more firm understanding of the impact of the variables (i.e., tractor ground speed, terrain slope) on its response (engine load) for the three fields (i.e., Been, Creek, and West Bisland). Again, the results represented the effect of all the main factors and their interactions on the engine load utilizing the tractor CAN Bus.

The results of the Been field indicate a significant effect ($b$ = 4.012, $p < 0.01$) of ground speed on engine percent load. Slope angle was also significantly associated with engine percent load ($b$ =3.65, $p < 0.05$). The model accounted for 97% of the variance in engine load. For the Creek field, regression results suggest that both ground speed and slope angle were significantly associated with ($p < 0.01$) engine percent load. This model accounted for 98% of the variance in fuel rate. Regression results for West Bisland field suggest that both speed ($b$ = 2.748, $p < 0.01$) and slope ($b$ = 1.94, $p < 0.01$) were significantly associated with engine percent load. Results regarding the interaction indicate that the relationship between ground speed and engine percent load vary as a function of slope for the West Bisland field. This model accounted for 99% of the variance in engine percent load. These results demonstrate that both ground speed and slope angle have a significant effect for engine percent load across fields (Table 4.5).

Table 4.5 Regression analysis for field-related engine percent load.

| Field | Variable | Beta Coefficient | $P$ | $R^2$ |
|---|---|---|---|---|
| Been | | | | |
| | *Constant* | *29.42* | | *0970* |
| | *Speed* | *4.012* | *0.000* | |
| | *Slope* | *3.650* | *0.042* | |
| | *Speed × Slope* | *0.140* | *0.390* | |
| Creek | | | | |
| | *Constant* | *34.79* | | *0.980* |
| | *Speed* | *2.939* | *0.000* | |
| | *Slope* | *3.769* | *0.001* | |
| | *Speed × Slope* | *0.119* | *0.211* | |
| West Bisland | | | | |
| | *Constant* | *37.51* | | *0.988* |
| | *Speed* | *2.748* | *0.000* | |
| | *Slope* | *1.937* | *0.014* | |
| | *Speed × Slope* | *0.250* | *0.000* | |

The following regression equations and Figure 4.24 to Figure 4.27 explaining engine percent load regarding ground speed and slope angle.

Been:

`Engine Percent load (%) = 29.42 + 4.012 Speed + 3.65 Slope + 0.148 Speed*Slope`

$$R^2 = 0.970 \qquad (4)$$

Creek:

`Engine Percent load (%) = 34.79 + 2.939 Speed + 3.769 Slope + 0.1191 Speed*Slope`

$$R^2 = 0.980 \qquad (5)$$

W Bisland:

`Engine Percent load (%) = 37.51 + 2.748 Speed + 1.937 Slope + 0.2499 Speed*Slope`

$$R^2 = 0.988 \qquad (6)$$

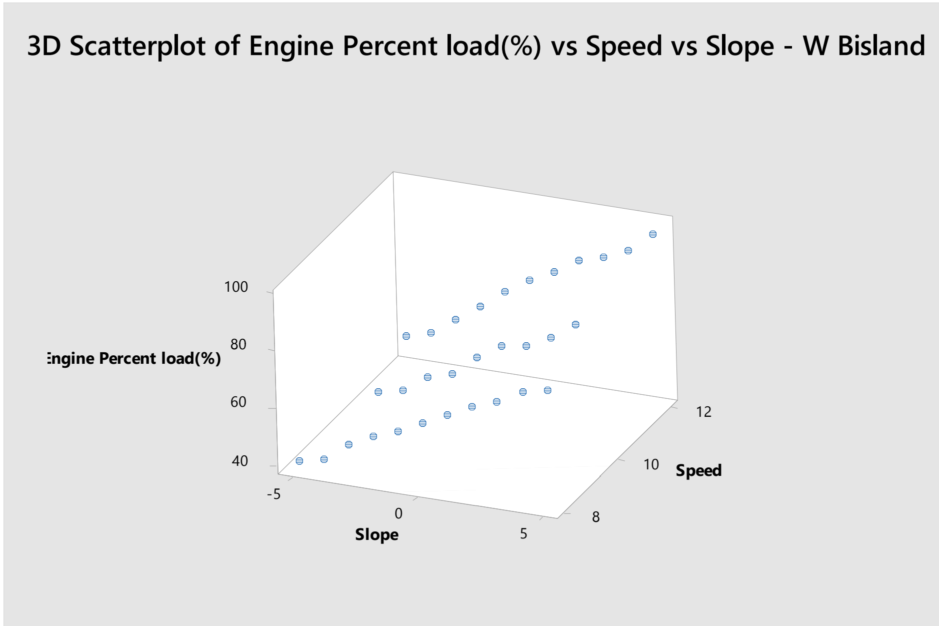


Figure 4.24. The relationship between engine load, three slopes, and three speeds for the West Bisland field.

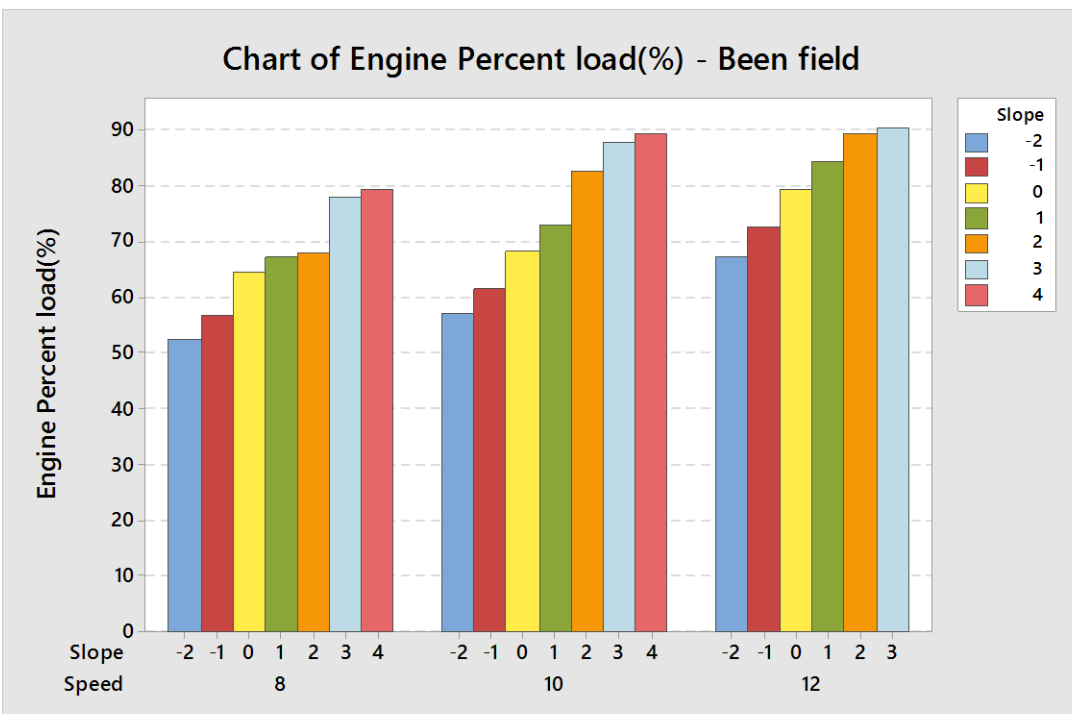


Figure 4.25. The effect of three practical speeds and differing slope on engine percent load for the Been field.

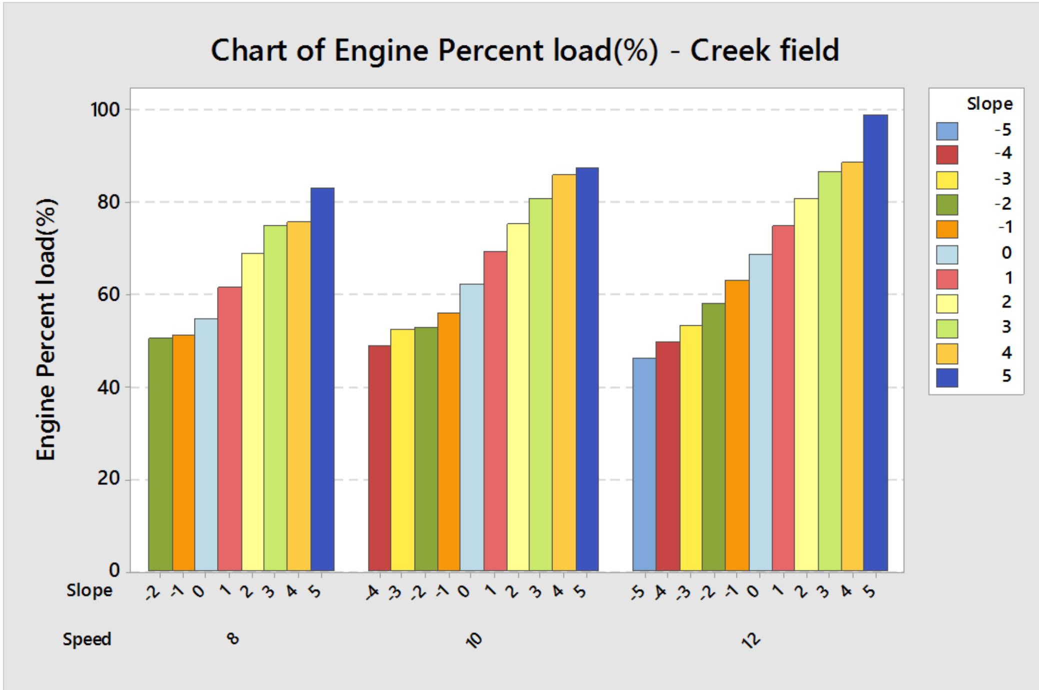


Figure 4.26. The effect of three practical speeds and differing slope on engine percent load for the Creek field.

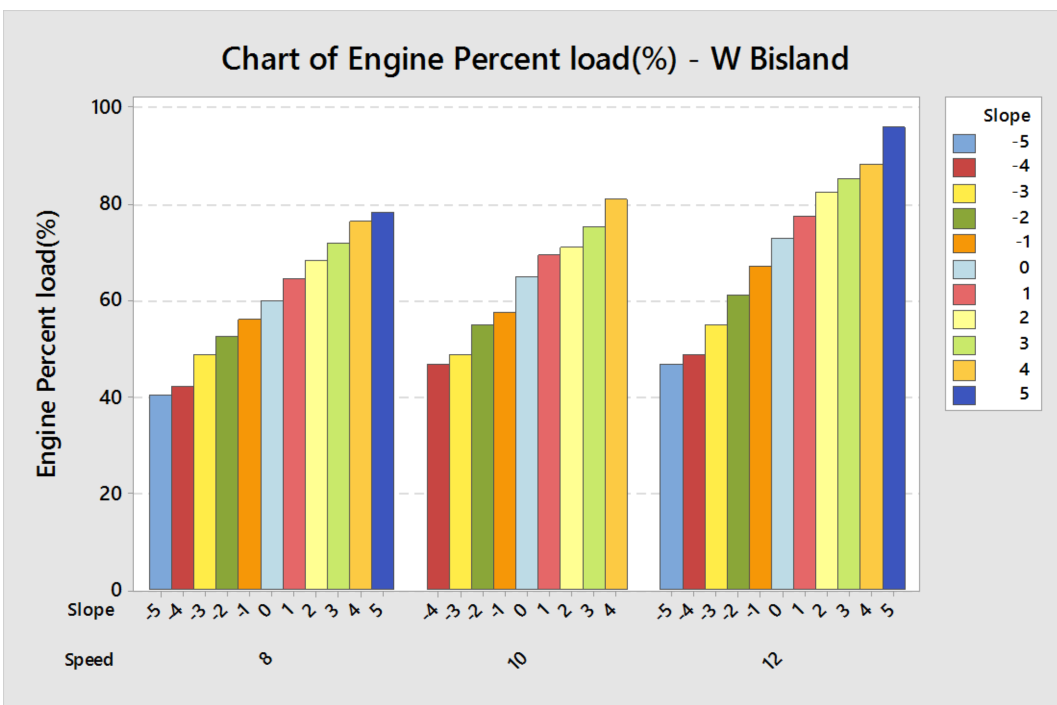


Figure 4.27. The effect of three practical speeds and differing slope on engine percent load for the West Bisland field.

The above results are consistent with our expectations about the effect of practical speed and slope on engine percent load. The bar chart of the West Bisland field (Figure 4.27) elucidates the averages of engine load in three different ground speeds and slope angles treatment. On the x-axis, three fields' ground speeds of the tractor (8, 10, and 12 km/h) are given with respect to the slope of the terrain (from -5 to zero and then to +5 angles) for the three fields. The y-axis quantifies the engine percent load (%) in a range of 0 to 100%. In the case of West Bisland field, on the treatment of slope zero for the first speed (8 km/h), engine percent load was 60%. For 10 km/h, for the same slope, the engine percent load increased to about 65%. A similar effect was noticed in the engine percent load as increased to about 73% when the tractor ground speed reached 12 km/h. The above results met the expectations. The engine percent load for each treatment was calculated directly from the CAN Bus. The effect of ground speed, as related to pitch angle, as they are presented in Figure 4.24 to Figure 4.27. The engine percent load for each treatment was calculated directly from the CAN Bus. The effect of ground speed, as related to pitch angle, as they are presented in Figure 4.25 to Figure 4.7. It is apparent that tractor engine percent load lined up with both tractor ground speed and pitch angle. Engine percent load was generally lowest for declining terrain (negative slope degree) whereas the values of engine percent load were highest for inclined terrain (positive slope degree). The total engine load for the different ground speeds and different slopes is presented in Figure 4.25 to Figure 4.27 . It is apparent that tractor engine percent load lined up with both tractor ground speed and pitch angle. Engine percent load was generally lowest for declining terrain (negative slope degree), whereas the values of engine percent load were highest for inclined terrain (positive slope degree). The total engine load for the different ground speeds and different slopes is presented in Figure 4.25 to Figure 4.27.

From the results shown in figures 4.25 to 4.27, we can discern that the lowest engine percent load was reached in speed 8 km/h and the negative slope degree (-5) in the case of West Bisland field. In contrast, the highest engine percent load was observed on the highest positive angles (+5) compared to both flat and negative angles. It can be noticed that a similar pattern occurred for all treatment combinations for both other speeds for all three fields.

This study indicates that engine percent load was 41% for the declined slope (-5) and 8 km/h. The level of engine percent load rose gradually to about 60 % for flat degree (zero) and continued to gradually increase to about 79% in the end of the positive slope (+5).

## 4.6 Conclusions

This project demonstrated the successful adoption of using CAN Bus system to develop a measurement tool. CAN Bus technology can determine the performance indicators in different vehicle ground speeds in a wide range of terrain or slope angles. The results of this study suggest that measuring field performance parameters is achievable. The following conclusions were drawn from this project:

1. The total system, which was developed to analyze machine operations, functioned well and provided sufficient results to measure parameters of interest (i.e., fuel rate and engine percent load).
2. As expected, these results illustrate the relative contribution of each independent variables (i.e., tractor ground speed and slope) on the dependent variables (i.e., fuel rate and engine percent load) across different fields. Speed and slope highly affected both engine fuel rate and engine percent load across three fields.
3. As a point of interest, it can be concluded that CAN Bus provided a unique solution to common issues in measuring and monitoring agricultural machinery.

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# CHAPTER 5. DESIGN AND EVALUATION OF COURSE IMPROVEMENT AND STUDENT PERCEPTION LEARNING PERFORMANCE FOR CONTROLLER AREA NETWORK

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## 5.1 Abstract

Controller Area Network (CAN) Bus technology has increased in popularity in the industrial sector. Recently, many research studies have been conducted to further utilize and investigate this technology in the agricultural sector. These new advancements in CAN Bus technology require professionals to engage in specialized training to gain knowledge. Feedback from industry suggested that preparing agricultural engineering students to have skills in CAN Bus technology would help the industry. Viability of approaches to teach CAN Bus that yield favorable outcomes for learners, educators, and the industry was investigated. A mixed-methods approach, through qualitative and quantitative student feedback on surveys, were applied to evaluate student learning outcomes of students enrolled in a university CAN Bus course. The class, Electronic Systems Integration for Agricultural Machinery and Production Systems (ABE 410/510), is offered in the Department of Agricultural and Biosystems Engineering (ABE) at Iowa State University (ISU). Three data collection tools were applied in this study: (1) pre- and post- surveys (2) a midterm course survey; and (3) weekly journals where students wrote about their ongoing learning in the course. Findings indicated that student self-assessment in the classroom can be a useful method for measuring the value added by a program of study and for improving student learning outcome.

## 5.2 Introduction

Technological systems are vital for nearly all agricultural businesses. These systems help with project planning, task organization, reduction in cost of operations, and promotion of growth in agricultural industries. The development of the research that is described in chapters 1, 2, 3, and 4 of this dissertation led to discussions about how to teach CAN Bus technology to ABE students, how to identify implementation to student learning, and how to identify areas for pedagogical improvement.

Many instructors use technology in the classroom to prepare better students for a job market (Allenby et al., 2009; Velazquez et al., 2006). For example, in the ABE 410/510 course students learn how CAN high (CANH) and CAN low (CANL) generate signals as a function along with a CAN master board in order to obtain a message that can help them analyze text data (Darr et al., 2007).

Another element in which instructors are interested in assessing their teaching effectiveness through course assessments and other evaluations (Steward et al., 2004). With these evaluations, instructors can determine student learning difficulties, viable approaches that can improve student learning, and the most effective ways to deliver course materials and communicate clearly with students.

Instructors can assess students in a variety of ways throughout the semester (Black et al., 2005; Huba et al., 2000; Steward et al., 2004). For example, students can write weekly journals, fill out course evaluations, and answer pre-and post-assessments. These assessments can be used as indicators for class outcomes of student learning (Boston, 2002).

The current study had the following objectives:

1- Determine the effectiveness of approaches that could enhance student learning of electronic system integration for agricultural machinery (CAN Bus).
2- Assess how students learn through reflection surveys, and the relationship with the approaches used to evaluate the effectiveness of the teaching method implication.

## 5.3 Background

Three decades ago, CAN Bus technology did not exist and farmers relied on traditional analog devices to measure agricultural machinery performance. These analog devices are costly, time consuming, and labor intensive. For example, to measure fuel consumption for a machine in the field, a well trained personnel had to use an externally connected device and make modifications to the engine to perform the measurement. Often, this method did not yield accurate nor instantaneous results. Similarly, analog measurement of torque, speed, load, draft, was also problematic.

The development of CAN Bus technology has replaced traditional methods with technology that is more efficient. CAN Bus technology is cost effective, time efficient, and does not require human labor. In addition, such things as speed, torque, and fuel rate can be measured accurately and instantly through electronic circuit units (ECUs) that utilize CAN Bus technology (Darr et al., 2007).

## 5.4 Teaching a CAN Bus and Systems Integration Course

Feedback from the industry sector suggests that preparing agricultural engineering students to have mixed skills and experiences in computer applications and agricultural engineering would help the industry (Zwickle et al., 2014). Additionally, mechanical and hydraulic engineering knowledge and understanding of how vehicle units communicate with control systems are also needed.

Students experience the importance of learning CAN Bus technology when they are offered internships in industry or when they learn about required knowledge in posted job descriptions. Thus students become motivated to learn about CAN Bus. ABE 410/510 has experienced an increase in enrollment over time because of this.

Many agricultural engineering students are hired as systems engineers because their broad backgrounds and internship experiences. ABE 410/510 was developed to meet industry needs for this type of graduate (Bhandari et al., 2011). For instance, Dr. Darr from Iowa State University (ISU) developed a course on Ag machinery and CAN Bus technology.

### 5.5 The Importance of Developing and Teaching an Electronic Systems Integration for Agricultural Machinery and Production Systems

First and foremost, feedback from key industry partners in the last 10 years suggests that the agricultural sector needs more systems engineers. Yet, due to the lack of professionals with an expertise in systems engineering, it is common for the industry to hire computer scientists to perform software development and agricultural engineers to perform machinery management. A professional with an expertise in both areas should be able to perform both tasks.

In the last three decades, agricultural machinery designs involve software, hydraulics, cable networks, and machinery management. Thus, agricultural machinery manufacturers experience difficulties in finding qualified engineers that have the aforementioned mix of knowledge. In the off-road machinery sector, the understanding of basic vehicle networks and the communication between control systems and hydraulics is now required. The ABE 410/510 course (Electronic Systems Integration for Agricultural Machinery and Production Systems) meets that need.

### 5.6 ABE410/510 Course Features and Development

ABE 410/510 course was first offered in 2008 and has evolved over time. Early versions of the course started with explaining the basics about microcontrollers as well as some basic programming. Currently, the material of this class incorporates a wide variety of concepts that qualify students to perform tasks at the industry level. Students learn about electronic devices, hydraulic systems, control systems, and machinery management. An intermediate level of computer programming knowledge is now an essential course prerequisite because students in the class develop codes that can control all ECUs in agricultural machinery.

Additionally, students in the class have access to tools such as Vector cards, Canoe software, Communication Application Programming Language (CAPL), and Matlab. Two fully equipped laboratories (an embedded systems laboratory and hydraulic systems laboratory) are used for this course to give students a real experience of industry environment as well as allowing them to implement their own projects. Course content was organized to build students' skills and knowledge gradually from simple to more complex topics. Sequencing the subject matter enhances students' learning outcomes by building their skills on one another (Fink, 2003; Sharma et al., 2017).

### 5.7 University Course Description

Electronic Systems Integration for Agricultural Machinery and Production Systems is a course offered by ISU's Department of Agricultural and Biosystems Engineering (ABE) at both the undergraduate (ABE 410) and graduate (ABE 510) levels. It is an elective course that attracts students from engineering programs outside the department (e.g., mechanical, electrical, and computer) as well as computer science. The course is offered at least once a year, based on student demand with class sizes of 30 to 40 students.

The syllabi for both courses informs that the emphasis is on information technology and systems integration for automated agriculture processes. Students learn about the design of Controller Area Network (CAN BUS) communication systems and discuss relevant standards such as ISO 11783 and SAE J1939. The course focuses on the application of technologies for sensing, distributed control, and automation of agricultural machinery and electro-hydraulic systems. Typically, course content is delivered through two hours of lectures per week, followed by two or more hours of laboratory work. The course is divided into three modules as explained in the next section.

Graduate students taking ABE 510 are required to complete all the work required of undergraduate students in ABE 410. Additionally, graduate students must submit an individual project and complete more advanced laboratory work. The syllabus can be found in Appendix D.

## 5.8 Course Modules

Both ABE 410/510 are divided down into three major modules based on the number of weeks and topics as shown below:

### 5.8.1 Module 1: Weeks 1 – 5

The goal of the first five weeks in this course is to teach students the basics of CAN Bus technology, CAN Bus topology, and networking. In general, most of the ABE students enrolled in ABE 410/510 have not taken a course in digital communication and software applications. Thus, it is important to teach the basic concepts at the beginning of the class. For instance, Figure 5.1 below shows CAN message output generated in an oscilloscope. Students are expected to look at this CAN message output and locate the information shown in the Identifier, Data, CAN High, CAN low, and Low Voltage Differential Signaling (LVDS) displays. They should then be able to interpret the 0's and 1's and start building some basic visual logical process.

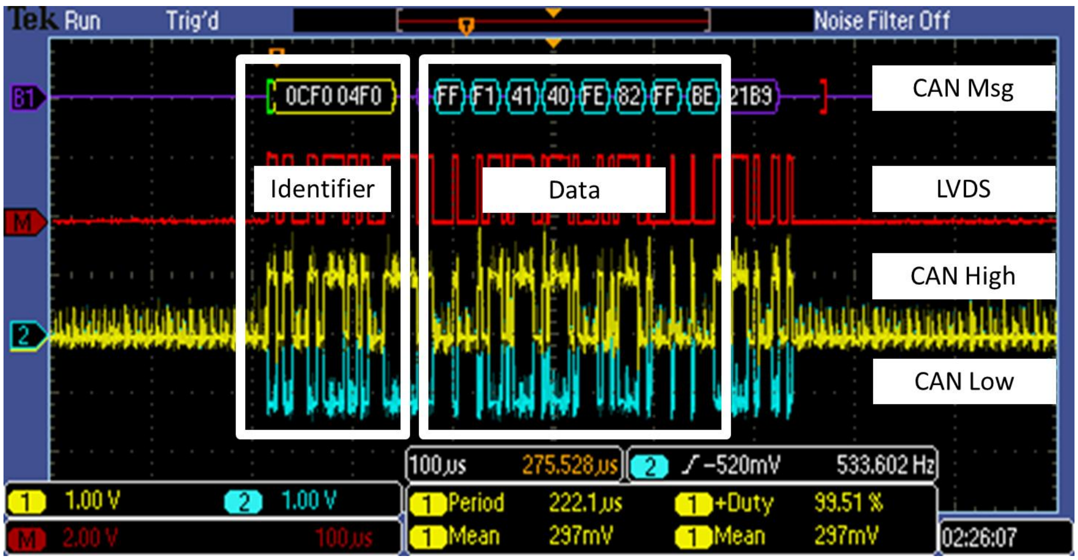


Figure 5.1. CAN message output as viewed by an Oscilloscope (Darr, 2012).

Due to the fact that most ABE students have limited knowledge about these basic concepts when they come to class, the first five weeks also includes some basic computer engineering skills, such as binary and hexadecimal numbers. In these initial weeks, some students struggle with the basic terminologies and concepts.

Students are looking for information they can use in field application. The first five weeks of the class (module1) introduce students to CAN message definitions and standards (J1939 and ISO11783). Then students can begin to use CAN Bus systems.

The first laboratory assignments in Module include development of a digital dashboard to visualize engine speed, PTO speed, fuel rate, torque, and engine hours by using basic J1939 messages (Figure 5.2 and 5.3). Students realize that they can convert 1's and 0's through standard documents into useful performance indicators. These lab assignments build students' confidence through interactions with actual live CAN Bus systems and develop student competence in analyzing CAN data.

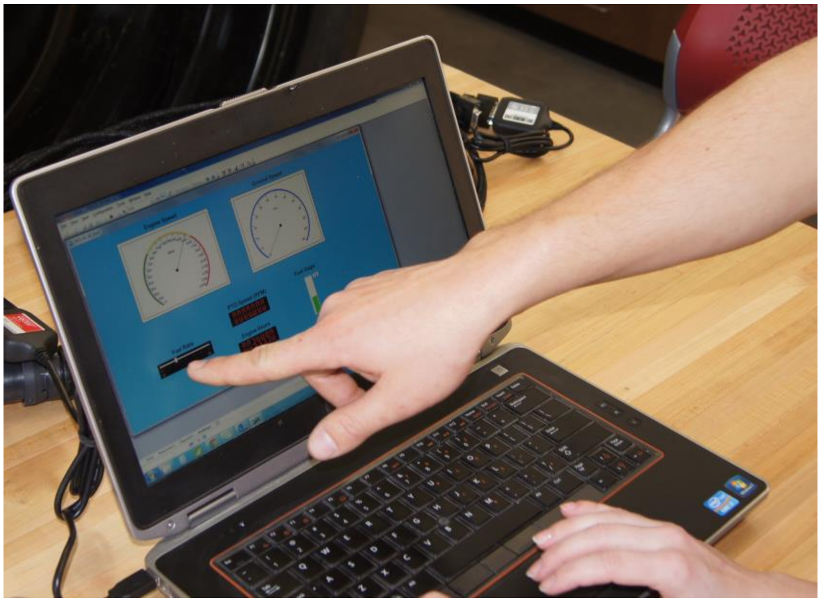

Figure 5.2. Students creating a dashboard and panel design to display machine performance indicators.

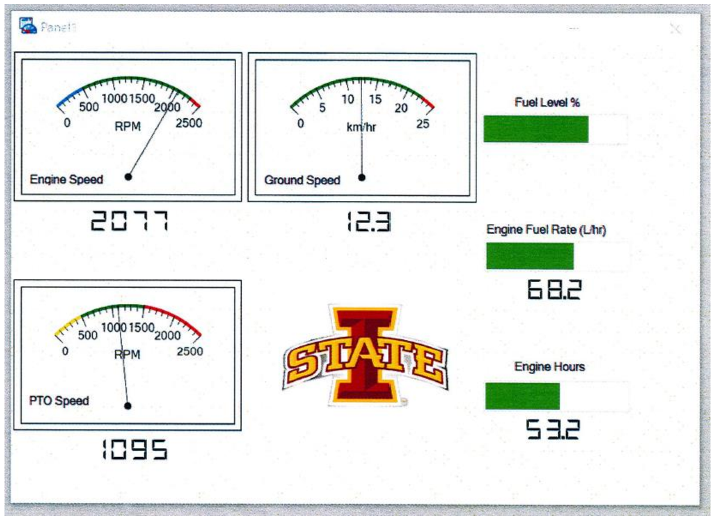


Figure 5.3. Final version of a student-created dashboard for machine performance indicators.


Figure 5.4. Students using their dashboards to monitor parameters for their laboratory study.

Figure 5.5. Students test their dashboard on a different tractor under instructor’s supervision.

Every student works on laptop computers to build their programs (Figure 5.4 and Figure 5.5). They attach the computer to the tractor diagnostic port and monitor the changing performance parameters. Students repeat this process for different tractors. From that, students realize that the standards are recommendations and not requirements.

### 5.8.2 Module 2: Weeks 6 – 10

In the second module of the course, students build their own vehicle network using CAN Bus systems. By plugging a CAN based joystick controller (Figure 5.6) in to a single laptop, students are able to control and communicate with fluid power components assembled in a fluid power trainer (e.g., hydraulics cylinders with a feedback messages, motors and valves) (Figure 5.7). At this point, students construct their circuits. Instead of sending and receiving signals (like a honk), students have the JS7000 dual axis joysticks (Figure 5.6) which communicate via  CAN Bus that they can use to send a command to their computer to drive the components of the system. This is a very important stage for the students. First of all, when the cylinder does not move, students must decide if this is a CAN Bus issue from the joystick, or a software issue, or something related to valves not moving. In other words, this module helps students build diagnostic and troubleshooting skills to help them find solutions. While they communicate though the strainers to find solutions.

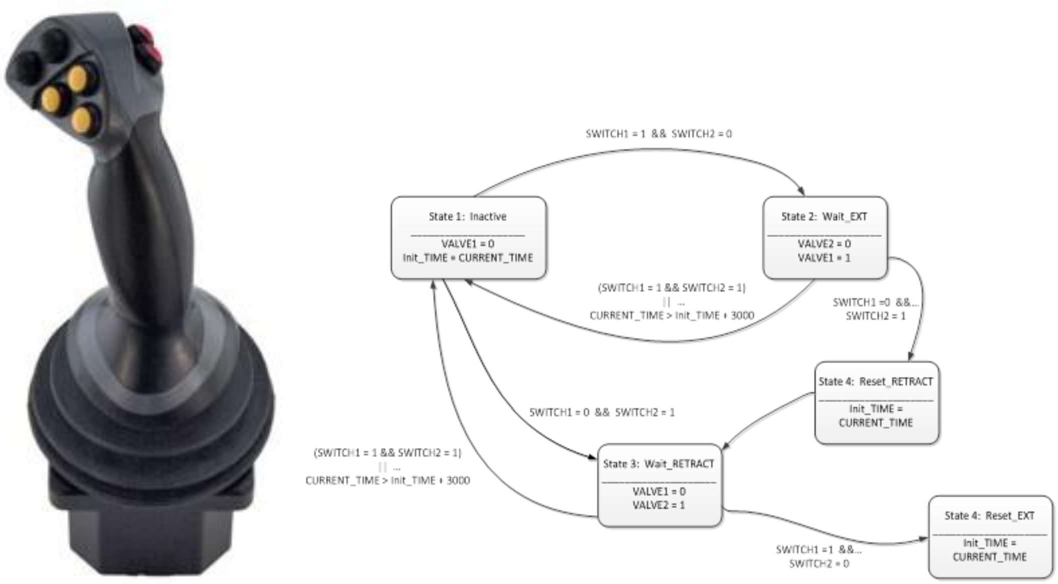


Figure 5.6. The JS7000 dual axis joystick is used as an input device on the trainer (Darr, 2017).

In this module, students gain hands on experience with vehicle control networks. By pressing buttons, student see reactions happened. These weeks help students to understand the principles of network management, multi-node systems, state machines, and model based software development.

The laboratory exercises of this module reinforce the concept and help them develop competence in state based hydraulic system control over a distributed CAN network. Students also gain experience in generating performance and defect reports based on CAN data and demonstrate competence in J1939 and ISOBUS Standards.

Figure 5.7. Hydraulic trainer components in the lab.

### 5.8.3 Module 3: Weeks 11 – 15

In the last four to five weeks of classes, students start working on their final projects and build proficiency in team based state machine control of a multi-point vehicle control system. In this module, the students use knowledge from previous weeks' laboratory exercises. Students complete an accurate representation of a functioning and simulating combine harvester as a real life situation. Each team creates codes for their own system effectively communicates with other individual stations (Figure 5.7) to send and receive the CAN messages.

Every station in the laboratory represents a portion of the combine system. Units should be connected to each other and contact between these stations to exchange the information. During the last module, students build a multi-point machine control project, which emphasizes engineering communication, and shared team documentation.

Figure 5.8. Hydraulic lab.

## 5.9 Student Learning Outcomes

Upon successfully completing this course, students should have gained a or improved their :

• Proficiency in CAN Bus networks and interpretation of CAN Bus data. Student should be able to walk to a tractor, understand how the vehicle CAN Bus functions, and have general principles on how ECUs communicated in the network and talk to each other.

• Proficiency in production of analytical results and reports derived from electronic communication on agricultural vehicles based on data collected. After capturing CAN log and be able to use a Matlab, Excel, SQL, or any other tools to generate a report from CAN systems.

• Ability to integrate hardware and software components to achieve high performance, distributed sensor networking to support agricultural information technology. Understanding the state machine and some system design requirements. Also, in this class, talking about some standards J1939, ISO 11783 and show their applications in this class.

• Proficiency of the system design and technologies required by fully integrated electrical, mechanical, and fluid systems.

• Understanding of ISO11783 and J1939 engineering standards and their role in open connectivity of agricultural machinery.

• Proficiency in design and implementation of automated state machines for machine function control.

## 5.10 Methodology

The development of the course under study was entitled Electronic Systems Integration for Agricultural Machinery and Production Systems, (ABE 410/510). This course was offered within the Department of Agricultural and Biosystems Engineering at Iowa State University

(ISU) in spring of 2018 under the instruction of Dr. Matt Darr. The ABE 410/510 class was selected for the following unique reasons: (1) today's electronic systems are virtually of the same core functionality in the industry as engines, systems, brakes, and others; (2) it is composed of multiple engineering disciplinary students, (3) and the syllabus consisted different engineering tasks related to different engineering disciplines. The class under study has been offered every other year since 2008, with an average of 40 enrolled students at junior, senior, and graduate levels. For better learning outcome, the class was split into three major modules as described in "Course Modules" section. The three-credit class met once every week in a 110-min lecture and 110-min laboratory session. In the year the class was under study, it had an enrollment of 32 undergraduate and graduate engineering students in Computer, Mechanical, Electrical, and Agricultural and Biosystems Engineering.

For the purpose of this study, three multidisciplinary assessment tools were used. Each individual student was asked to submit feedback through (a) pre- and post-course assessment questionnaires, (b) weekly "lessons learned" journals and reflections, and (c) end-of-term survey. Students were informed of their rights to opt out of the assessment in accordance with the Institutional Review Board (IRB) at Iowa State University. Data were analyzed and compared after the students completed these assessments and all identifiable information was removed from the dataset.

### 5.10.1 Pre- and Post-assessment

Pre- and post-assessment was conducted to help design and filter course content and to gauge students' learning progress in the ABE 410/510 course and to ensure successful class administration and teaching implementation. After students completed a certain amount of course work, lectures, and activities in the class, formative and summative evaluations and assessments were provided (Newton, 1999). Pre-and-post-assessments were created with class outcomes in mind. Pre-and-post-assessments were specifically designed by the authors to be given to students at a specific entry point and exit point: at the beginning of the course before students encountered the course content and after the course had concluded. The pre-assessment was a formative evaluation given to students as a variety of questions (7 questions) about the content taught during the course. Of all open ended questions provided in the pre-post-assessment, three questions which directly inquired about the students' knowledge of course content were analyzed in the study. The first question of the three asked about the students' CAN Bus knowledge. The second question asked the students about their knowledge of ISO 11783 and J1939 standards. The last question was about students' backgrounds in monitoring and controlling machines. These questions helped assess students' levels of confidence in mastering the course material. Responses in the pre-assessment helped the instructor identify students' weak and strong points in the material and required skills. Based on that, the instructor could modify the course activities accordingly. These activities were a combination of lectures, exercises, assignments, activities, and group work.

On the other hand, extra-curricular class work was assigned for areas of weakness identified by the assessment. At end of semester, in the post-assessment questionnaire, improvements in students learning outcome were measured. Progress measured by the assessment is presented in the Results and Discussion as (Bishop-Clark et al., 2012).

There are several purposes and advantages for conducting the pre-and post-assessments. First, the pre-assessment helps the instructor know the entry status of a group such as their level in the course prerequisites which guides him/her in designing course activities. It also helps the instructor know how deep and how much background knowledge they needs to build for these groups, and how much content needs to be provided before moving to more advanced subjects (International Training and Education Center of Health, 2010).

### 5.10.2 Lessons Learned Notebook

All students were required to maintain a course notebook, either physically or electronically. The notebook contained all reports and results from the course as well as an inventory of lessons learned about weekly topics. Students were required to prepare a weekly technical journal which included key lessons learned. Each notebook included at least all the following: techniques, tips, example solutions, and key new knowledge learned. These documents were sorted by week and accumulated over the entire semester. The intent of this notebook was to provide a reference throughout the semester which supported lab activities in the project portion of the course.

The notebook was submitted weekly to provide feedback to both: students and instructors. It was graded collectively with the midterm and at the end of the semester. The notebook contained a section on course notes, laboratory, homework assignments, and the lessons learned journal. Each section was to be ordered chronologically to match the course plan.

Of all questions asked of the students, the focus of our study specifically addressed three questions. The first question asked the students about what helped them learn. The second question asked the students for their reflections on the Panel lab. The last question asked about their reflections on the coding and programming laboratory.

### 5.10.3 Course Surveys

Course surveys are a well-known method that have been used to evaluate student perceptions of how they achieved learning outcomes. We applied this methodology in ABE410/510. After the midterm exam, students were asked to complete an anonymous survey. The purpose of this survey was to ask students about what they perceived as the most efficient method that helped them learn. Since the survey was administered during midterm time, students were more confident in the method they selected, given the longer period for this survey. The results of the survey helped evaluate the pool of methods used during the course. More emphasis will be given to the more effective ones in future years.

The survey consisted of 26 items. For the purpose of this study, we focused on three items because they were key topics. There were two forms of the survey, a paper form which was handed to students in class and a digital form ‘e-survey’ which was accessible through the course page. The survey contained a mixed method approach consisting of quantitative and qualitative questions. Some of the questions used a Likert-type scale ranging from 1 to 5 (1- not useful, 2- somewhat useful, 3- useful, 4- very useful, 5- important). Qualitative questions were open-ended text responses. Generally, the survey included three points of interest to achieve the learning outcomes of the course:

- The first point of interest included questions about how much knowledge and technical skills students had gained thus far in the class.
- The second point of interest included questions on what key enablers helped students learn and what factors hindered their learning.
- The third and last point was on students’ suggestions and feedback to better understand students’ perceptions about the course content and the teaching methods. Having a

diverse group of students as we had in class provided a rich response of ideas and suggestions due to multidisciplinary prospective on the survey's points of interest.

The data which were collected from the survey in spring 2018 were analyzed to aid the instructor in understanding the students learning.

## 5.11 Results and Discussion

The instructor of the 2018 ABE410/510 class implemented and conducted the assessment and evaluation practices described above. Below the results of each of the three methods are presented in separate sections along with discussion of each.

### 5.11.1 Pre-and Post-assessment

The pre-and post-assessment was used as an instrument to measure the students' level of knowledge, skills, and attitudes before and after taking the ABE 410/510 class. In the first day of classes, before instructions began, the pre-assessments was administered. The outcomes were based on students' self-assessments of the level of knowledge they had in three of the topics covered in the class: CAN Bus, J1939 and ISO11783 standards, and machine control. A plan of instructions was developed and tuned to address the amount of needed attention to be paid to which topic.

At end of class, the same assessment was administered to students. This post-assessment gauged the development of the students' attitudes towards the topics and their feelings towards meeting the goals and outcomes of the class. Pre- and post-assessment results in both offerings were divided into major and sub-major divisions through the survey.

In the pre-and post-assessment, 28 out the 32 enrolled students participated. The pie chart below (Figure 5.9) shows the choices made by the students in the pre-class assessment administration. The first question in the self-assessment asked students what they knew about

CAN Bus. The pre-course survey showed that 71% of the students did not know anything about CAN Bus, 18% of the class knew little but were unsure, 7% had moderate knowledge, and 4% had good idea about CAN Bus. For example, one student indicated in their response: “Just that’s it’s a relatively cheap system used on vehicles and equipment”.  Another student said “I know very little about CAN’s”. Another student mentioned that it is “On-Board software and hardware used in vehicles.”

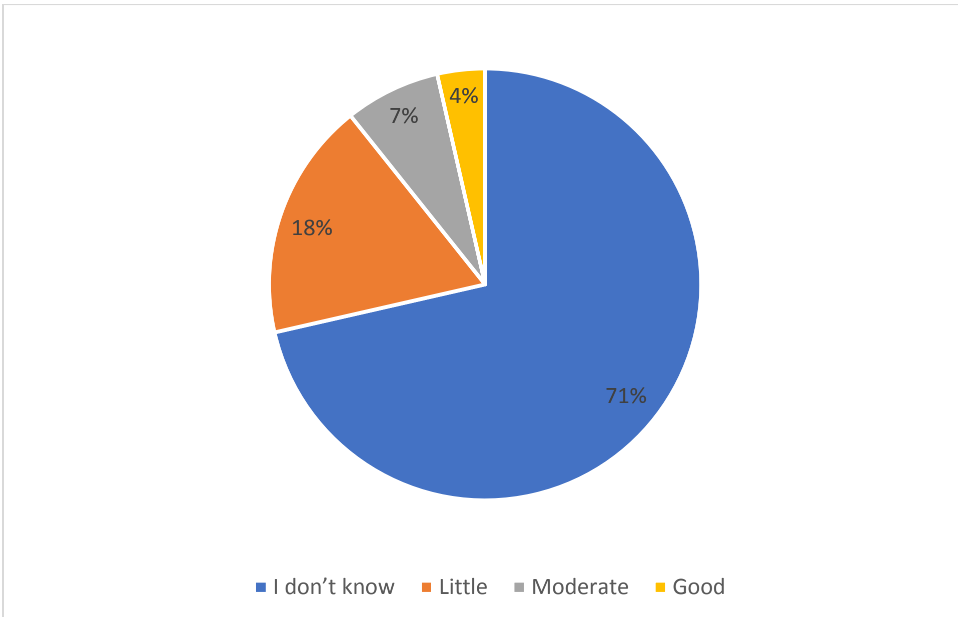


Figure 5.9. Percentage of student responses to the pre-assessment question, “What do you know about CAN?”

In the post-class assessment, 100% of the students answered that they became more familiar with the main functions, the components of CAN Bus, and how the network communicates between controllers and sensors in the vehicles and automotive industry. One student commented that:

> “CAN is a form of electronic communication between multiple ECUs. It is very common in automotive and agricultural vehicles to transfer diagnostic and control

information repeatedly. A CAN message is a chunk of data on the CAN bus that represents a certain piece of information. CAN signals are the individual pieces of data that represent something meaningful about the machine."

With respect to the second topic, the question was about how well students increased their knowledge on standards. Through analysis of students' responses in the second question for the pre-assessment, it was found that 71% of the students were not aware of ISO 11783 and J1939 standards. Another 13% of students did not know much, and 8% of students said that they had "good" or "skilled" knowledge of these standards (Figure 5.10). For example, one student wrote "I don't have any knowledge of J1939 or ISO 11783 standard." Another student said "No knowledge".

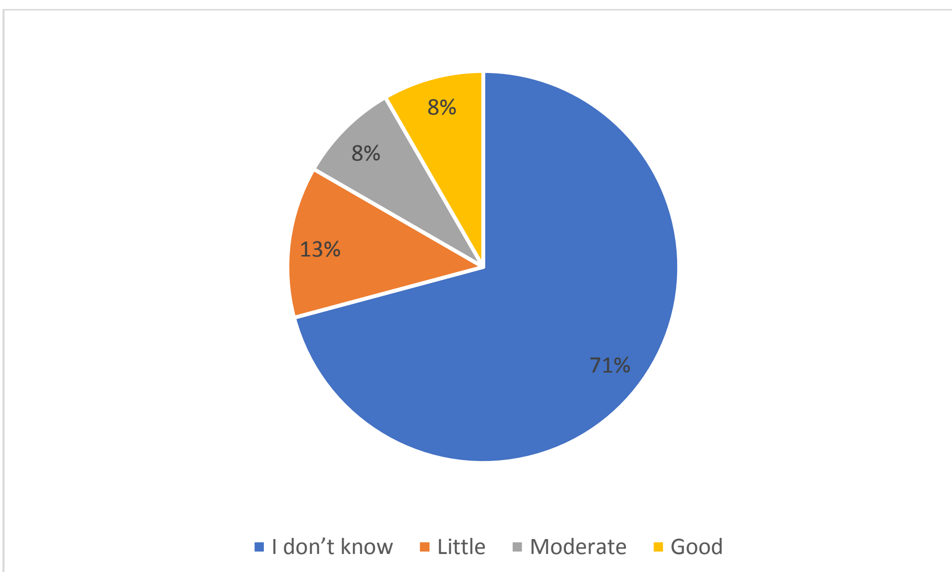


Figure 5.10. Percentage of student responses to the pre-assessment question, "Do you have any knowledge about J1939 or ISO 11783 standards?"

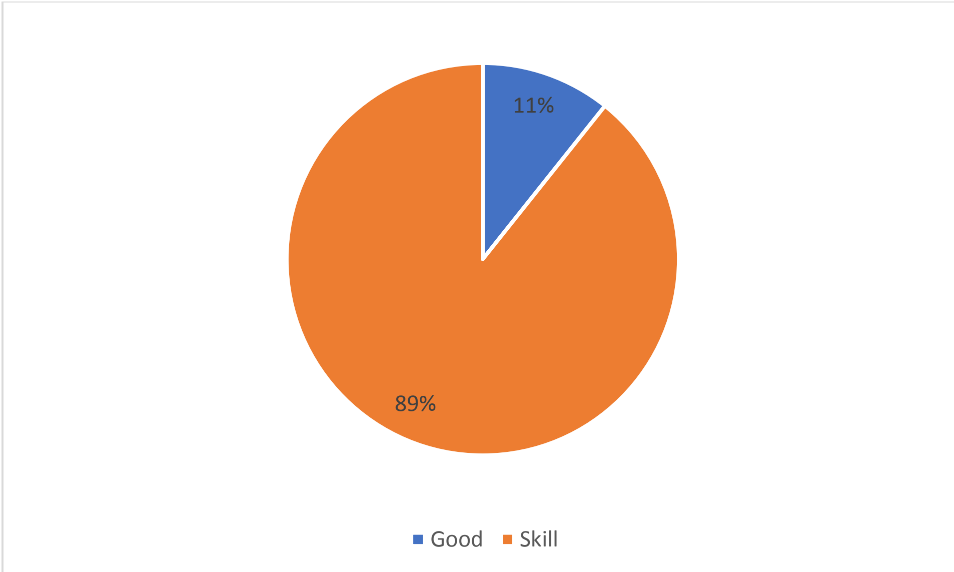


Figure 5.11. Percentage of student self-assessment responses to post-assessment question, “Do you have any knowledge about J1939 or ISO 11783 standards?'

It can be clearly seen from the chart of students’ responses in the post-self-assessment (Figure 5.11), the largest majority percentage (89%) of the students said that they were “skilled” and 11% said that their knowledge of the standard was “good”. For instance, one student commented:

> “I have (sic) no any knowledge about J1939 or ISO 11783 before this class. Now I know a lot of about them. The Society of Automotive Engineers standard SAE J1939 is widely used to standardized communication and diagnostics on vehicles. SAE J1939 further standardizes the CAN Data Frame to subset the Identifier into specific application categories as well as defining the physical wiring, baud rate, and network management of CAN data. SAE J1939 requires the use of the Extended Format messages with a 250 kbit/sec baud rate. ISO 11783 adopts the SAE J1939 standards and extends it to off-road vehicles. In addition to inheriting the SAE J1939 Data Frame structure, ISO 11783 defines the physical wiring and standardized electronic

connections, network management, and advanced implementation layers. The advanced implementation layers include off-road specific applications including a virtual terminal display, a specific Tractor ECU bridge, a task controller for data management, and advanced diagnostic services.".

Another student wrote

"Yes, 11783 is an ISO standard used by agriculture and heavy equipment. This standard is in place so that all things can communicate. An example would be a Deere planter on a case tractor, with the standard in place, the planter will still be able to talk to the virtual terminal in the tractor."

A closer analysis of the responses from students about controlling and monitoring machines, is shown in Figure 5.12. The figure revealed that there was a divergence in opinion about this topic. More than half of students (54%) were not familiar with machine controlling and monitoring.

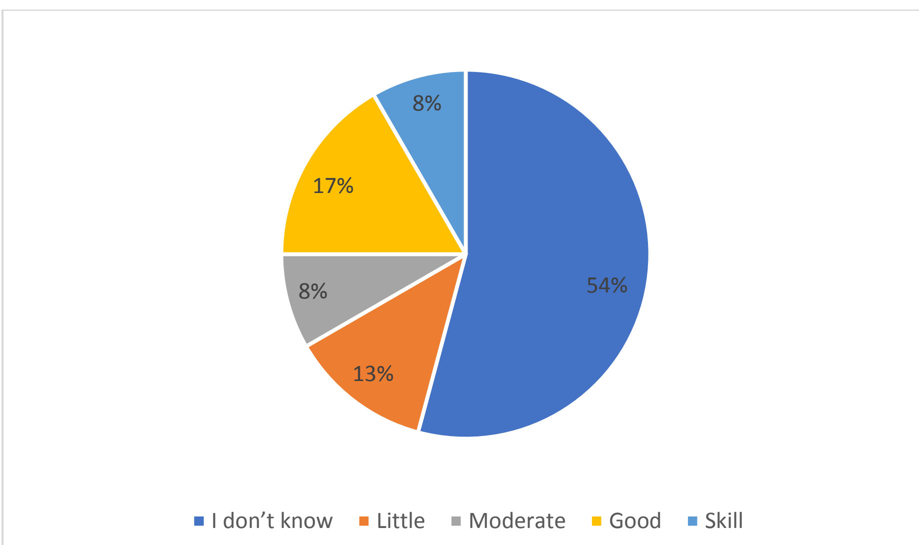


Figure 5.12. Percentage of student self-assessment responses to pre-assessment question, ' Do you have any knowledge about controlling and monitoring machines?'.

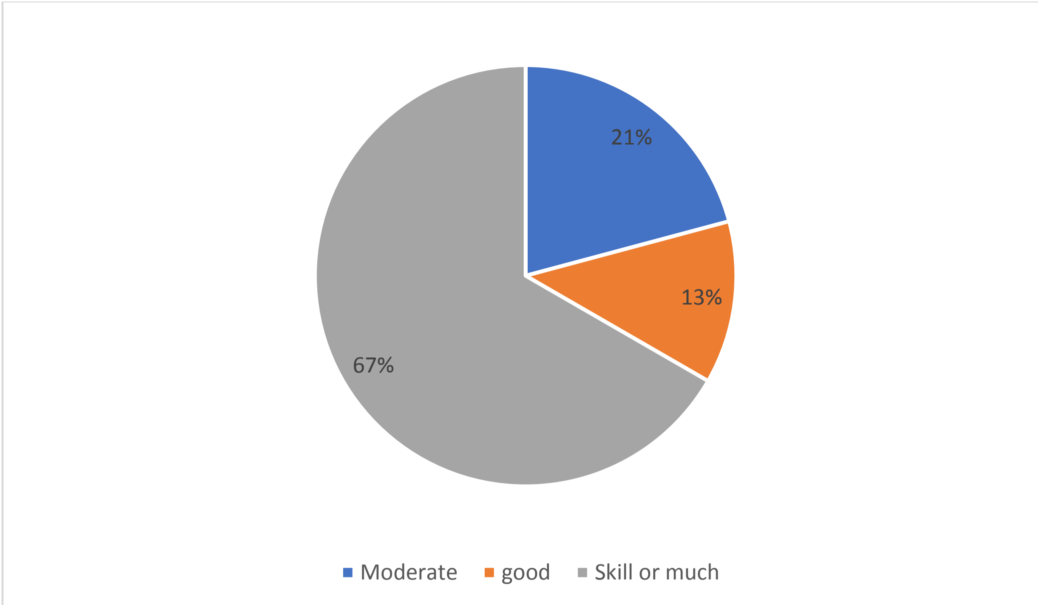


Figure 5.13. Percentage of student self-assessment to post-assessment question, ' Do you have any knowledge about controlling and monitoring machines?’.

For example a student said, “I have some knowledge about controlling and monitoring machines. I grew up on a farm and worked as a mechanic at a New Holland dealership for multiple summers.” Another student indicated that “I did a little bit of hydraulic controls during my co-op at Altec.” Another student summarized his/her answer by “Not really”.

The analysis of student post self-assessment showed that 67% of students became more comfortable monitoring machines as the students evaluated themselves. The second and third largest percentages were 21% (moderate) and 13% (good) of students corresponded, respectively (Figure 5.13). For example, one student stated, “Before the class, I had no ideas about controlling and monitoring machines. Now I know some about those. I know how to use close or open loop to control the machine. For example, we actually use error signal to control the close loop system”. Another student mentioned that “Yes, this class helped me in controlling and monitoring machines, such as: running and controlling cylinders, motors, etc.”

Pre- and- post assessment is a popular method for professors to assess prior knowledge and then to assess how well the learners are understanding during the course in a practical sense. Conducting this fast feedback and simple assessment is a good indicator for learning processes and outcomes for both instructor and students. This formative assessment allows both of them to be aware of barriers in the learning process and to make immediate changes in a practical sense. The measure that was used indicated whether or not students were learning. The results revealed their own self-assessment of how much they knew about the topics. The responses of students' self-assessments to the CAN Bus concept and knowledge confirms development in students' understandings. The self-assessments indicated improvement from 71% of students that indicated they (don't know anything) and 18% (know little) to 100% of students indicated that they have a deeper insight and global understanding about this technology.

Similarly, findings results from pre-and-post-assessment for specific questions about standards indicated additional emphasis on student learning. Student provided quite different responses about this topic. Students' self-reported pre-assessment indicated that 71% of students mentioned that they (don't know) about standards, 13% of students indicated that (know little), 8% had a (moderate) knowledge, and the last 8% said that they have (good) understanding. Students' self-assessment responses were improved in the post-self-assessment. 89% of students became (good) and 11% indicated that they are (skilled). When students were asked in pre-self-assessment about controlling and monitoring machines, 54% of student (don't know), 17% were (good), 13% (know little), and 8% were (skilled). In students-post assessment, overall, the majority of student increased to 67% (skill). The second highest percentage was 21% (moderate) and the third percentage 13% (good). This is a good indicator about the effectiveness of course structure and content and how student's self-assessments might be attributed to students learning.

### 5.11.2 Weekly Lessons Learned

Weekly lessons learned journals were used as a weekly progress report and as a frequent communication tool with the instructor about student learning. Student feedback was used on a regular basis from the instructor to identify issues that could be addressed and solved on a weekly basis. Thus, the instructor could better prepare materials for the next class. Conducting this valuable strategy into weekly routine and giving thoughtful attention to student feedback about their own work was important to academic progress and to increase the students' motivation to learn (Steward et al., 2005). All students benefited from this activity and helped the instructors to investigate and develop student learning especially in the major assignments.

Introducing the notion of weekly lessons provided the students an opportunity to write down what they did not understand in each assignment. Each week the instructor analyzed the student's reflections and used them to clarify these muddiest points and bridge the previous class content during the next class.

The first important lesson learned identified from the first reflection question was that most students strongly agreed that putting students in groups during labs helped explain the topic and the assignment. This theme emerged because students discussed the difficult topics with each other. According to the students' perspectives, working in groups not only helped them to understand the material better, but also taught them to think about the challenges they experienced. For example, one student commented about one of the major assignment in the course, Joystick Control lab: "Nothing currently unclear but having the display show the gear speed on the monitor, and calibrating the Y-axis position and the speed was challenging. But, I worked with others in my group and I learned from them." Another comment was "This was a fun lab because I worked with others. Being able to control a display through the use of a joystick and having button presses beep and control gear was fascinating". Another student wrote "The joystick serves as an important hardware for controlling agriculture machinery. It consists up to 5 primary buttons and movable axis in X and Y directions which can be used to control movement of machinery. These lab experiments have made me to understand how CAN messages are transmitted in the network and how I can utilize the hardware and Communication Application Programming Language (CAPL) to create an automotive sub system". This effective way reflected students' perspective on ongoing basis about individual assignments. This positive approach provided students opportunities to integrate the feedback they received to produce better products.

The second reflection question asked students about the Panel lab. When the students were asked about the Panel lab the highest percentage of their feedback proved that this lab is very useful in their learning. Figure 5.14 summarizes students' self-assessments. Notably, 88% of students strongly agreed that this topic enhanced their understanding and improved their thinking about implications of the knowledge about the lab. This activity helped students understand how communication occurred between the systems. Additionally, this assignment helped students built their experience by interacting with a CAN based joystick controller to send different messages on the bus. It is also helped students better visualize what is occurring while changing real-time data through CANoe.

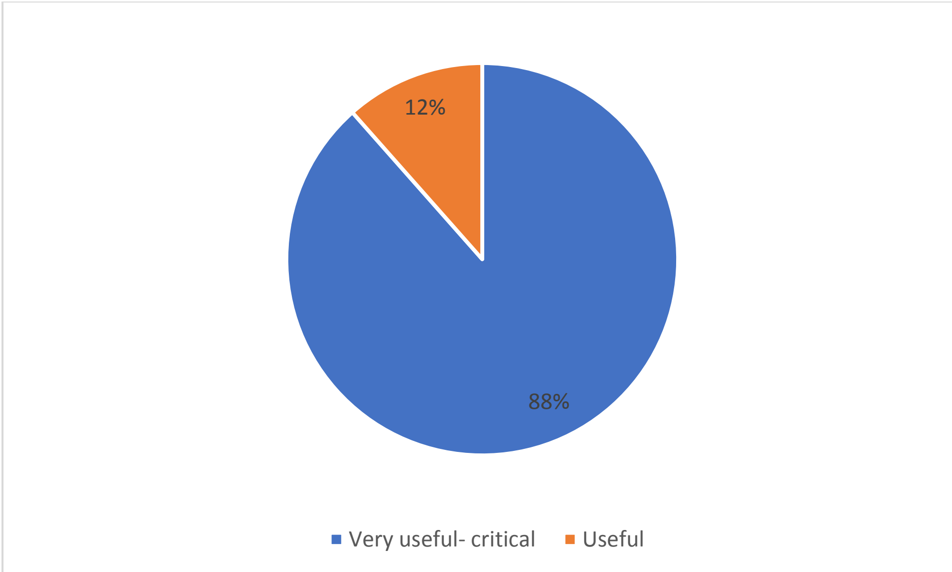


Figure 5.14. Percentage of student self-assessment responses to the question: What enhanced your learning this week (panel lab)?

For example, one student commented:

"The main ideas in this lab are: 1-Panels are useful for visualizing the live data coming through. 2- You get as much out as you put in, if you spend a lot of time on your panel it will help you out in the long run. 3- Panels are not just for output, it can also be used as inputs that can be used by canoe. The important results are: 1-After learning about panels I am able to successfully make panels to visualize virtually anything on the CAN bus. 2-The easy part is making the panel show the data, what I found to be the hardest is making it visually appealing and structured in a way that makes sense. What enhanced my learning in this lab: The lab that we hooked up to a live tractor really helped. I found that there was a real difference between replaying a log. The aspect of real time problem solving was really introduced here. What is most unclear in this lab: At the time it was introduced I was a tad unclear about getting inputs from the panel into canoe, but they were all cleared up by the start of our final project."

Another student wrote, “Exposure and hands-on experience with CANoe were great for learning this week. To learn a tool it is best to actively use the tool while learning. Not much was unclear, one tricky aspect from this week was setting up global system variables so that they could be displayed on the Panel.”

One final example from a student “The largest enhancement to my learning was learning how to create a panel in Vector CANoe. This allows the visualization of each message in real time, and is a good tool. Very little from this week was unclear. It was a great week of learning!”. This lab helped students perceive a tangible improvement.

The third reflection question was about program coding. Based on students’ responses having a basic pre-written code was important for their learning. For example, a student wrote “..honestly the most helpful for me. It minimized troubleshooting and small syntax errors that detract from learning what I was actually trying to do. It also gave the ability to add to the code and play around with the tools. The other thing that helped me learn was using real data from a tractor and not something synthetic and easy to work with. This gave me a feeling for what I need to expect when working with CAN data. Walking through CANoe in multiple steps was helpful instead of jumping straight to the live bus with the tractor. It allowed us to become more familiar with the software before doing too much to avoid confusion. Having the TAs walk through the group during the live bus portion was also helpful since we had a lot of problems with feedback from a connected replay block.

These assignments enabled students’ to grasp general understanding about data processing. The weekly lesson learned worked in one of the two ways. In the first, student wrote down the key important messages for each week. The other way to use the instructor to determine student weaknesses on a weekly basis. Many professors utilize this method to assess how well the learners are understanding during the course, and the instructor can make adjustments based on students' feedback. Conducting this simple method to provide fast feedback is a good indicator of meaningful learning for both instructor and students. This formative assessment allows both of them to be aware of barriers in the learning process and to make immediate changes. Due to the fact that this class is multidisciplinary, the wide range of students' responses shaped the direction of the course content. Timely updates on students' comments, suggestions, and opinions informed the instructor of the students' barriers for the past week assignments. Weekly lessons learned strategy allowed the instructor to pool vital evidence to evaluate students' learning processes and to made some adjustments. It was observed that regular feedback improved students' knowledge considerably (Steward et al., 2005).

### 5.11.3 Course Survey

Student feedback was collected through a course survey and used to improve course, teaching, and program design. The students explained why they liked the topics of interest and labs, or how these activities could be improved by giving specific examples and offering suggestions. The students' feedback was completely anonymous, and results were available to the instructors only after the final grades were submitted. The first topic of interest in our study was to ask students an open-ended question about what course structure or experiences they enjoyed in ABE410/510 class. Through evaluation of student feedback about structure or experiences that were a factor in their learning (Figure 5.15), it was found that 36% of the students indicated that the lectures were the most helpful for them, 25% of students mentioned that the final project was a key factor, 18% said the real tractor was the most useful, 11% said the joystick lab, 7% preferred the Panel, and 4% for the hydraulic trainers. The goal of final project was to combine students' knowledge together throughout the semester and allowed them to demonstrate their new found knowledge to achieve the tasks. In this project, students collaborated as a teamwork and used hydraulic trainers and CANoe to build a combine simulator that connected to global bus. The global bus had main subsystems including cab control, threshing system, engine and steering, unload system, and header system. This approach was beneficial as students' responses provided the instructor information about students' preferences that facilitate their learning.

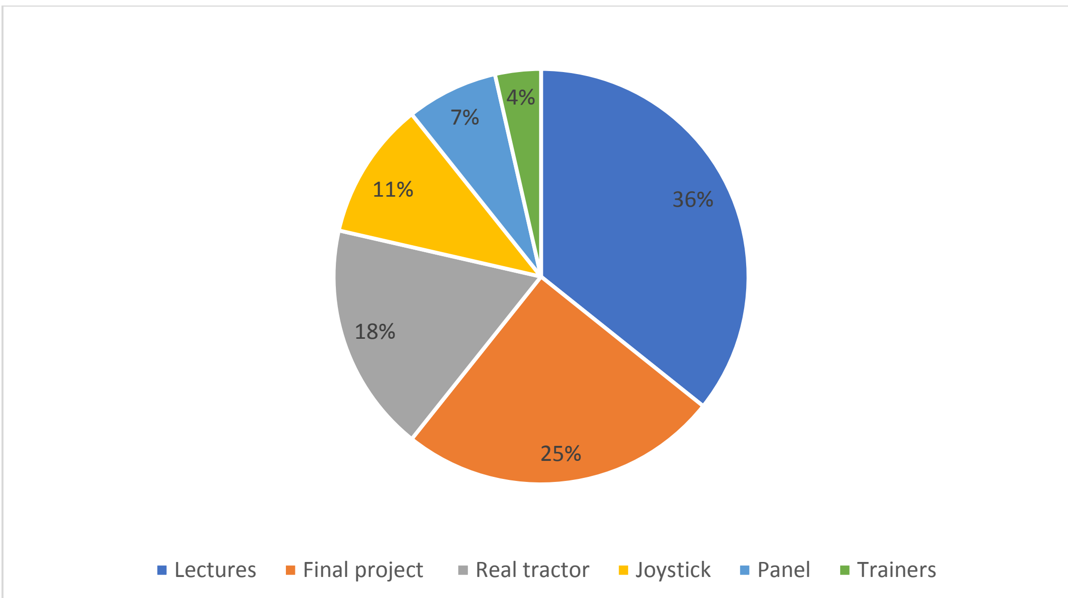


Figure 5.15. Percentage of student responses in the course survey to the question,' what course structure and experiences are helping me meet the learning outcome?

In one case, a student wrote: "The instructor clearly explained and provided course materials to learn how to interpret CAN data. The class had a lot of hands on learning which- while sometimes tedious- led me to be confident of the material". Another student indicated:" having a full package of resources helped me focus on the class and go back to detailed and correct answers when needed". From these comments, we conclude that the material provided for the students was valuable and helped the students focus on what was important during the class.

The first analysis was used to determine student perceptions for environment in lecture and lab components to support agricultural information technology. This was a quality analysis that was performed using the Likert-type scale approach to gather and analyze student perceptions. In this common rating format, students were asked to rank their responses in five alternative levels from high to low with 1 as strongly agree and 5 as strongly disagree. Students could explain why they chose this rating.

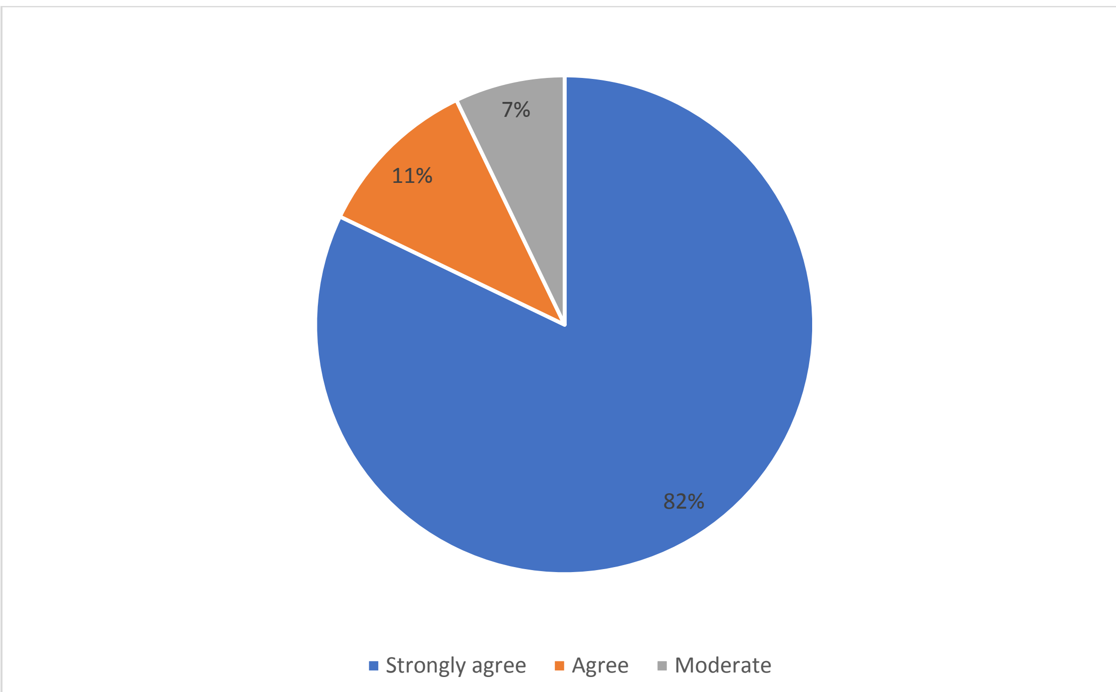


Figure 5.16. Percentage of student responses in the course survey to the question,' The overall environment in ABE410-510 is helpful for my learning'.

Overall, 28 students completed the survey where 100% of the students found that the environment of the course was helpful for their learning. Through evaluation of student feedback about class environment, it was found that most students (82%) 'strongly agreed" that the class environment facilitated their learning. Other students' percentage was 11%

"agreed" in their feedback that the environment was a core in their learning (Figure 5.16). For example, a student mentioned: "The environment was able to get us to interact and counteract each other's weakness. We always discussed our thoughts in the class. Dr. Darr was always very patient to discuss with us." Another student wrote: "People participated and it was a healthy learning environment. I could say that I can interpret CAN Bus data since based on how comfortable I was doing the assignments." Based on these comments, it is possible to conclude that class participation is important to the students' learning.

These questions were an indicator about student's satisfaction for the environment and how to improve the class. As is so often true, the most important educational value was to know the students' opinions about a particular topic over the semester and what their blind spots were. Thus, this was a road map that the instructor used to gain better ideas if any changes were required in the next step.

## 5.12 Limitations and Future Work Summary

We used this study to examine students' weaknesses and difficulties by analyzing meaningful feedback from students. Instructors were able to immediately, on a weekly basis, identify and address questions about course content that may not have been presented clearly and to make any necessary adjustments to their teaching methods. This helped the faculty and teaching assistants quickly identify any issues that were occurring in certain lectures, recitations, or laboratory sections, and address them in a timely manner.

Through the course, the instructor worked with students to overcome any barriers and enable students to make progress towards the learning outcomes. The key lessons learned:

• Students responded very positively to exposure to current production vehicle electronic systems.  This led to increased student engagement and increased confidence in student skills.

• It is very important for students to have a voice and ideas in the course, particularly in challenging subjects.

• Looking at students' performances during the class to compare their performance with class expectations helped students become more successful learners and enhanced students achievements.

• Students responded very positively to exposure to current production vehicle electronic systems.  This led to increased student engagement and increased confidence in student skills.

• The multi-station controls project was a great opportunity to build engineering team communication skills in students.

• Students had more success achieving the learning objectives through higher level system integration solutions rather than through a heavier software emphasis, but both are needed.

• Conducting surveys gave students an opportunity to write and express their comments, suggestions, and opinions

Some limitations were observed in our study, such as:

- The fact that the students came from a wide range of majors, for both undergraduate and graduate level, needs to be considered to examine the effect of the discipline and the academic level of the student.

- Not all the students completed the survey. One of the reasons can be attributed to the fact that the survey was given at the end of the semester, when the students are usually busier, compared to the beginning of the semester.
- The blind survey was an obstacle to study the relationship between students' scores and students' self-assessments.
- Repeating the survey for different semesters could provide better inputs.
- Future research effort is recommended to bolster these class assessments.
- The small number of students in the study affected performing statistical data analyses.
- Additionally, the lack of students enrolled in this class prevented the comparison between a control group and a treatment group to obtain more meaningful results.

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# CHAPTER 6. GENERAL CONCLUSION

Agricultural machinery is an essential part of creating viable solutions to the great challenges of meeting human food security. Agricultural mechanization has been growing and developing over the past several decades contributing to increase efficiency, productivity, and durability.

The current evolution and adaptation of these technologies integrating agricultural equipment and farming practices is key to meeting sustainable global food needs. Development of systems is enabling agriculture to enter a new era with the capability of transmitting real time data and monitoring the tasks. The adaption of data acquisition systems provides growers with accurate and essential information about field operations, enhancing their ability to achieve more improved solutions.

Farm Management Information System (FMIS) is a new data processing and recordkeeping technology. This technology can be used effectively to capture, treat, store, and manage electronic information, thus enabling farmers to make better decisions. Developing and adopting modern technologies, such as data logging, is critical to providing precise information about agricultural machinery performance. Data acquisition is one of the most crucial technologies to provide operators with physical quantities. These measurements will help operators evaluate, analyze, and manage the performance of machines at various field conditions.

Currently, with software development and the demand of using larger, heavier agricultural machinery to cover larger areas, new techniques are needed to help users evaluate the performance of their machines, instead of traditional methods. CAN Bus technologies can be used to design management systems for global agricultural operations and designated tasks.

Ultimately, these configurations and data structures provide farm owners with accurate and succinct data, giving them the ability to integrate and manage performance data for agricultural machines and improve the management of machines. Further, these configurations can also archive information about field operation tasks. Thus, CAN Bus can also help farmers oversee the machinery working process, visualize the data, and establish optimal decisions.

Recently, advancements in data acquisition systems for monitoring agricultural tractors performance and activities are enabling researchers to improve machines management. These systems have a crucial role in measuring and visualizing information about agricultural vehicles. This technology can help maintain a high level of optimization through adjusting engine load, engine speed, fuel consumption, vehicle location, radar speed, time, engine temperature, and fuel temperature. Due to the increasing use of CAN Bus, educating future machine designers on its use and value is important.

The purpose of each individual project in this study was to validate use of digital agriculture and data logging to improve machine performance, instead of traditional and more complicated methods. The project was designed to provide more accurate and quicker feedback about agricultural machines during agrotechnical activities. More specifically, the study's purposes were:

1- To develop methods and protocols to directly quantify the power requirements of agricultural machines utilizing electronic vehicle networks.

2- To estimate machines' capacity and utilization based on automatic data analysis from agricultural machinery.

3- To demonstrate the use of an agricultural machinery electronic system to calculate optimal configuration of agricultural machines.

4- To understand and investigate the most viable approaches to teach CAN bus that yields favorable outcomes for learners, educators, and the industry.

In chapter 2, “Background about Controller Area Network “CAN” Bus”, provided a general background, history, development, and the importance of CAN Bus. With recent software development and the demand for using larger and heavier agricultural machinery to cover larger areas, new techniques will be needed to help users evaluate the performance of their machines.

Controller Area Network (CAN Bus) technologies can be used to design management systems for global agricultural operations and designated tasks. Ultimately, these configurations and data structures provide farm owners with accurate and succinct data, giving them the ability to integrate and manage performance data for agricultural machines, thereby improving production processes. These configurations can also archive information about field operations tasks. Thus, CAN Bus can help farmers oversee the machinery working process, visualize these data, and establish optimal decisions.

In chapter 3, “The Performance of Farm Tractors as Reported by Can-Bus Messages, Tillage Project” demonstrated the use of CAN Bus to evaluate tractor performance in tillage applications. CAN Bus technology provides a simple to use, easy to install, high speed method of data collection that conveniently retrieves the stored data.

For that purpose, the four factors examined in this study were tractor weight, tractor tire inflation pressure, tillage depth, and percentage of engine power usage. Tire inflation pressures were set for 21- 22 psi (all tires) in the first treatment level, and 10- 11 psi for the front tire and 7-8 psi for the rear tire in the second treatment level. Two levels of tractor weight were used: static weight (19750 kg) and 2120 kg added weight (tractor weight). Tillage depth treatments of 7.62 cm and 12.7 cm were used. The engine power was controlled at two levels of 100% engine power usage and 70% engine power usage, as determined by the transmission gear selection.

A case study analysis of a field cultivator under multiple tractor and implement configurations was conducted in a (41) hectare field in Ames, Iowa, United States. The results showed a significant difference in fuel consumption due to engine power, tillage depth, tire inflation pressure, and interaction between tillage depth and engine power. However, after adjusting for multiple comparisons, no significant difference was shown between depths of 7.62 and 12.7 cm (86.21 L/h and 87.05 L/h respectively) on maximum power. In contrast, a significant difference was observed at low power for depths of 7.62 and 12.7 cm.

Additionally, a significant difference within depth was observed between maximum and 70% power. At depth 7.62 cm, the fuel rate for the maximum power was found to be 86.21 L/h, while the fuel rate for 70% power was 67.58 L/h. It is clear that increased tillage depth, involving increased soil disturbance leads to increased tractor load and fuel consumption.

At the standard weight, maximum fuel consumption (87.24 L/h) was observed at maximum power, with a maximum depth (12.7 cm), and maximum tire pressure. Likewise, for the same weight, the lowest fuel consumption (67.04 L/h) was observed at 70% power, low depth (7.62 cm), and low tire inflation pressure.

Moreover, in adding weight, the maximum fuel rate was observed at maximum power, high depth (12.7 cm), and high tire inflation pressure. Low fuel consumption was observed at low power, low depth (7.62 cm), and low tire inflation pressure. The results also show that engine power usage does not significantly impact fuel consumption.

Additionally, greater slippage percentage occurs at lower power usage and higher tillage depth. Moreover, for the added weight, the highest slippage percentage (19.80%) was observed at maximum tire inflation pressure, high depth (12.7 cm) and low power (70%). The lowest slippage percentage was observed at low tire pressure, low tillage depth, and 70% power usage. Thus, these techniques allow for substantial saving of money and time, reduced workload, elimination of training necessary for specialized measurement tools, and improved agricultural machine management.

In chapter 4, “Controller Area Network for Agricultural Planting Application” , electronic systems were used to track the performance and efficiency of agricultural machinery units on a real-time basis on flat, uphill, and downhill lands. This chapter was focused on use of the CAN Bus system in optimize a high speed John Deere field planter under varying terrain slopes to gain more accurate, real-time information about its performance.

This comprehensive method analyzes and interprets several performance parameters of agricultural machinery on a continuous basis. As such, it is an alternative approach to traditional methods of measuring the performance of agricultural mechanization. In this study, CAN data were collected to evaluate the performance analysis of fuel consumption, unit speed, and engine load based upon different tractor-planter configurations on both flat and sloping land. A combination of tractor-planter units was operated in three different fields with three different ground speeds on a wide slope land range. The tractor speeds were 8, 10, and 12 km/hr, while sloped angles ranged from -5 to +5 degrees. Based upon different tractor-planter configurations on flat and sloping terrains, the analysis demonstrated that both ground speed and slope angle have significant effects on the studied parameters.

Increases in unit speed were associated with increased levels of fuel rate. The engine percent load was generally lowest for declining terrain, whereas the values of engine percent load were highest for inclining terrain. This unique and powerful technology enables users to make better decisions and maximize mechanization performance for different agricultural operations and various ground surface conditions. When compared to traditional methods of measuring agricultural mechanization performance, CAN Bus technologies provide real-time monitoring and safer, more reliable measurements. This is a concrete demonstration of the practical advancements of CAN Bus which provided key machine performance indicators operating on absolutely flat and sloped fields. This protocol, which is becoming standard for communications technology dedicated to farm machinery, enables users to make better decisions and maximize mechanization performance for different agricultural operations and various ground surface conditions.

In chapter 5," Design and Evaluation of Course Improvement and Student Perception Learning Performance for Controller Area Network", draw attention to Controller Area Network (CAN) Bus technology's increased popularity in the industry sector. Recently, many studies have been conducted to further utilize and investigate this technology in agriculture. These new advancements in CAN Bus technology require professionals to engage in specialized training and gain more knowledge. Feedback from the industry sector suggests that preparing agricultural engineering students to have skills in CAN Bus technology would enable industry to be able to hire skilled graduates.

This part of the study investigated the most viable approaches to effectively teach CAN bus to learners, educators, and industry. A mixed-methods approach, such as learner-feedback surveys, was applied to evaluate student learning outcomes of students enrolled in a university course. The class, Electronic Systems Integration for Agricultural Machinery and Production Systems (ABE 410/510), is offered in the Department of Agricultural and Biosystems Engineering (ABE) at Iowa State University (ISU). Three data collection tools were applied in this study: (1) a pre- and post- survey, (2) a midterm course survey, and (3) weekly journals where students wrote about their ongoing learning in the course. Findings indicated that the advantages of conducting students' self-assessment in the classroom, as a useful method for measuring the value added by a program of study, with improved student learning outcomes.

The work presented in chapters 1, 2, 3, 4, and 5 suggested and provided a compreh-ensive solution to improve the performance of agrotechnical operations. Overall, this work can also be extended to estimate various other agricultural operations. This method can be applied when develop CAN Bus in young departments.

# APPENDIX A. [SQL CODE FOR TILLAGE]

```
DECLARE @ref_id int
SET @ref_id = 7228

select EngSpeed.ts_sec, EngSpeed.EngSpeed, Fuelrate.FuelRate,
EngineTorque.EngineTorque, EngPercentLoad.EngPercentLoad,
CurrentGear.CurrentGear,Year.Year,  Month.Month,  Day.Day, Hour.Hour,
Minutes.Minutes,
Latitude.Latitude, Longitude.Longitude,  NavigationBasedSpeed.NavigationBasedSpeed,
WheelBasedSpeed.WheelBasedSpeed , VehicleWeight.VehicleWeight
,EngineCoolingSysC.EngineCoolingSysC,
EngineFuelTempC.EngineFuelTempC , EngineOilPressureKpa.EngineOilPressureKpa

From
(Select ts_sec, AVG((d4*256 + d3)*.125) AS EngSpeed
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'f004'
AND channel = 1
Group by ts_sec) As EngSpeed

LEFT JOIN
(Select ts_sec, AVG(((d1*256) + d0)*.05) AS FuelRate
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEF2'
AND channel = 1
Group by ts_sec) As FuelRate On FuelRate.ts_sec = EngSpeed.ts_sec

LEFT JOIN
(Select ts_sec, AVG(d2-125) AS EngineTorque
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'F004'
AND channel = 1
Group by ts_sec) As EngineTorque On EngSpeed.ts_sec = EngineTorque.ts_sec

LEFT JOIN
(Select ts_sec, AVG(d2) AS EngPercentLoad
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'f003'
AND channel = 1
Group by ts_sec) As EngPercentLoad On EngSpeed.ts_sec = EngPercentLoad.ts_sec

LEFT JOIN
(Select ts_sec, AVG(d3-125) AS CurrentGear
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'f005'
AND channel = 1
Group by ts_sec) As CurrentGear On EngSpeed.ts_sec = CurrentGear.ts_sec
```

```
LEFT JOIN
 (Select ts_sec, AVG(d5+1985) AS Year
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEE6'
AND channel = 1
Group by ts_sec) As Year On EngSpeed.ts_sec = Year.ts_sec

LEFT JOIN
 (Select ts_sec, AVG(d3) AS Month
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEE6'
AND channel = 1
Group by ts_sec) As Month On EngSpeed.ts_sec = Month.ts_sec

LEFT JOIN
 (Select ts_sec, AVG(d4*.25) AS Day
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEE6'
AND channel = 1
Group by ts_sec) As Day On EngSpeed.ts_sec = Day.ts_sec

LEFT JOIN
 (Select ts_sec, AVG(d2) AS Hour
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEE6'
AND channel = 1
Group by ts_sec) As Hour On EngSpeed.ts_sec = Hour.ts_sec

LEFT JOIN
 (Select ts_sec, AVG(d1) AS Minutes
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEE6'
AND channel = 1
Group by ts_sec) As Minutes On EngSpeed.ts_sec = Minutes.ts_sec

LEFT JOIN
 (Select ts_sec, AVG(((d3 * 16777216.0 + d2 * 65536.0 + d1* 256.0 + d0 * 1.0) *
1/10000000) - 210)AS Latitude
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEF3'
AND channel = 2
Group by ts_sec) As Latitude On EngSpeed.ts_sec = Latitude.ts_sec

LEFT JOIN
 (Select ts_sec, AVG(((d7 * 16777216 + d6 * 65536 + d5* 256 + d4 * 1.0) * 1/10000000)
- 210)AS Longitude
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEF3'
AND channel = 2
```

```
Group by ts_sec) As Longitude On EngSpeed.ts_sec = Longitude.ts_sec

LEFT JOIN
 (Select ts_sec, AVG((d3*256 + d2)*0.0039062) AS NavigationBasedSpeed
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEE8'
AND channel = 1
Group by ts_sec) As NavigationBasedSpeed On EngSpeed.ts_sec =
NavigationBasedSpeed.ts_sec

LEFT JOIN
 (Select ts_sec, AVG((d2*256 + d1)*0.0039062) AS WheelBasedSpeed
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEF1'
AND channel = 1
Group by ts_sec) As WheelBasedSpeed On EngSpeed.ts_sec = WheelBasedSpeed.ts_sec

 LEFT JOIN
 (Select ts_sec, AVG(d0-256) AS VehicleWeight
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEEA'
AND channel = 1
Group by ts_sec) As VehicleWeight  On EngSpeed.ts_sec = VehicleWeight .ts_sec

LEFT JOIN
(Select ts_sec, AVG(d0-40) AS EngineCoolingSysC
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEEE'
AND channel = 1
Group by ts_sec) As EngineCoolingSysC On EngSpeed.ts_sec = EngineCoolingSysC.ts_sec

LEFT JOIN
(Select ts_sec, AVG(d1-40) AS EngineFuelTempC
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEEE'
AND channel = 1
Group by ts_sec) As EngineFuelTempC On EngSpeed.ts_sec = EngineFuelTempC.ts_sec

LEFT JOIN
(Select ts_sec, AVG(d3-4) AS EngineOilPressureKpa
From ISU_Internal_CAN.dbo.can_raw_data_tillage
where ref_id = @ref_id
AND pgn = 'FEEF'
AND channel = 1
Group by ts_sec) As EngineOilPressureKpa On EngSpeed.ts_sec =
EngineOilPressureKpa.ts_sec

WHERE EngSpeed.EngSpeed > 1500
Order By EngSpeed.ts_sec
```

For 70 % of Engine load

```
WHERE  EngSpeed.EngSpeed > 500
 AND  EngPercentLoad.EngPercentLoad > 50
 AND  EngPercentLoad.EngPercentLoad < 100
   Order By  EngSpeed.ts_sec
--------
```

## APPENDIX B. [SQL CODE FOR PLANTING]

```
-- Planting 2017 query to study the effect of pitch angle and terrain slope on some
performance indicators


DECLARE @ref_id INT
SET @ref_id = 26000  -- change to lowest value of ref_id

DECLARE @curr varchar(64)

while (@ref_id <= 30000) -- change to max value of ref_id
       begin


       Select distinct EngSpeedRpm.ts_sec, --Time stamp based off of enginer speed
message

  avg(EngSpeedRpm.EngSpeedRpm) over (partition by EngSpeedRpm.ts_sec) as
EngineSpeedRpm, --Engine speed averaged over 1 second
    avg(FuelRateLpH.FuelRateLpH) over (partition by EngSpeedRpm.ts_sec) as
FuelRateLpH, --Fuel consumption rate averaged over 1 second
  avg(Latitude.latitude) over (partition by EngSpeedRpm.ts_sec) as Latitude, --
Latitude of tractor averaged over 1 second
    avg(Longitude.Longitude) over (partition by EngSpeedRpm.ts_sec) as Longitude, --
Longitude of tractor averaged over 1 second
         EngineCoolingSysC.EngineCoolingSysC,
  EngineFuelTempC.EngineFuelTempC,
  EngineOilPressureKpa.EngineOilPressureKpa,
  avg(EngineTorqueP.EngineTorqueP) over (partition by EngSpeedRpm.ts_sec) as
EngineTorqueP,
  avg(EngPercentLoad.EngPercentLoad) over ( partition by EngSpeedRpm.ts_sec) as
EngPercentLoad,
  avg(NavigationBasedSpeedKmPh.NavigationBasedSpeedKmPh) over (partition by
EngSpeedRpm.ts_sec) as NavigationBasedSpeedKmPh,
  avg(WheelBasedSpeed.WheelBasedSpeed) over (partition by EngSpeedRpm.ts_sec) as
WheelBasedSpeed,
  avg(PitchD.PitchD) over (partition by EngSpeedRpm.ts_sec) as PitchD,
  --avg(CurrentGear.CurrentGear) over (partition by EngSpeedRpm.ts_sec) as
CurrentGear,
  --avg(VehicleWeight.VehicleWeight) over (partition by EngSpeedRpm.ts_sec) as
VehicleWeight,
  avg(Day.Day) over (partition by EngSpeedRpm.ts_sec) as Day,
  avg(Hour.Hour) over (partition by EngSpeedRpm.ts_sec) as Hour,
  avg(Minutes.Minutes) over (partition by EngSpeedRpm.ts_sec) as Minutes,
  avg(ElevationM.ElevationM) over (partition by EngSpeedRpm.ts_sec) as ElevationM,
  avg(Meter.MeterMotorSpdCmdRpm) over (partition by EngSpeedRpm.ts_sec) as
MeterSpeedRpm,
  --avg(SlipPercent.SlipPercent) over (partition by EngSpeedRpm.ts_sec) as SlipPercent

 (((avg(WheelBasedSpeed.WheelBasedSpeed) over (partition by EngSpeedRpm.ts_sec)) -
(avg(NavigationBasedSpeedKmPh.NavigationBasedSpeedKmPh) over (partition by
EngSpeedRpm.ts_sec)))/(avg(WheelBasedSpeed.WheelBasedSpeed) over (partition by
EngSpeedRpm.ts_sec)))*100 AS SlipPercent2
```

```
--Group by ts_sec) As SlipPercent On EngSpeedRpm.ts_sec = SlipPercent.ts_sec

       FROM
       (
       -- Using select statment to calculate tractor engine speed (rpm) by using its
PGN (F004)
(Select ts_sec, AVG((d4*256 + d3)*.125) AS EngSpeedRpm --include ts_sec collumn in
results table, cast the calculated average engine speed as EngSpeedRpm
FROM ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017 --database and table containing
WHERE ref_id = @ref_id --segments searched data down to just the active reference ID
AND pgn = 'F004' --PGN used for engine speed per ASTM J1939
AND channel = 1 --looks only at CAN data from the tractor bus
GROUP BY ts_sec, d3, d4 --groups results based first on ts_sec, then d3, then d4
) AS EngSpeedRpm -- Cast results with header EngSpeedRpm



    -- Using select statment to calculate engine fuel rate (L/h) by using its PGN
(FEF2)
LEFT JOIN
(Select ts_sec, AVG((d1*256 + d0)*.05) AS FuelRateLpH
FROM ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
WHERE ref_id = @ref_id
AND pgn = 'FEF2'
AND channel = 1
GROUP BY ts_sec, d0, d1
) AS FuelRateLpH ON FuelRateLpH.ts_sec = EngSpeedRpm.ts_sec  -- Only join results
table to EngSpeedRpm where collumns ts_sec have the same values



   -- Using select statment to calculate Latitude by using its PGN (FEF3)
LEFT JOIN
(Select ts_sec, AVG(((d3 * 16777216.0 + d2 * 65536.0 + d1* 256.0 + d0 * 1.0) *
1/10000000) - 210)AS Latitude
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEF3'
AND channel = 2
Group by ts_sec, d0, d1) As Latitude On Latitude.ts_sec = EngSpeedRpm.ts_sec


   -- Using select statment to calculate Longitude by using its PGN (FEF3)
LEFT JOIN
(Select ts_sec, AVG(((d7 * 16777216 + d6 * 65536 + d5* 256 + d4 * 1.0) * 1/10000000) -
210)AS Longitude
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEF3'
AND channel = 2
Group by ts_sec) As Longitude On Longitude.ts_sec = EngSpeedRpm.ts_sec
```

```
   -- Using select statment to calculate engine cooling tempreture (C) by using its
PGN (FEEE)
LEFT JOIN
(Select ts_sec, AVG(d0-40) AS EngineCoolingSysC
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEEE'
AND channel = 1
Group by ts_sec ) As EngineCoolingSysC On EngSpeedRpm.ts_sec =
EngineCoolingSysC.ts_sec


   -- Using select statment to calculate engine fuel tempreture (C) by using its PGN
(FEEE)
LEFT JOIN
(Select ts_sec, AVG(d1-40) AS EngineFuelTempC
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEEE'
AND channel = 1
Group by ts_sec) As EngineFuelTempC On EngSpeedRpm.ts_sec = EngineFuelTempC.ts_sec


   -- Using select statment to calculate engine oil pressure (Kpa) by using its PGN
(FEEF)
LEFT JOIN
(Select ts_sec, AVG(d3-4) AS EngineOilPressureKpa
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEEF'
AND channel = 1
Group by ts_sec) As EngineOilPressureKpa On EngSpeedRpm.ts_sec =
EngineOilPressureKpa.ts_sec



   -- Using select statment to calculate engine torque (%) by using its PGN (F004)
 LEFT JOIN
(Select ts_sec, AVG(d2-125 ) AS EngineTorqueP
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'F004'
AND channel = 1
Group by ts_sec) As EngineTorqueP On EngSpeedRpm.ts_sec = EngineTorqueP.ts_sec


   -- Using select statment to calculate engine percent load (%) by using its PGN
(F003)
LEFT JOIN
(Select ts_sec, AVG(d2) AS EngPercentLoad
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'f003'
AND channel = 1
Group by ts_sec) As EngPercentLoad On EngSpeedRpm.ts_sec = EngPercentLoad.ts_sec
```

```
   -- Using select statment to calculate navigation based speed (Km/h) by using its
PGN (FEE8)
LEFT JOIN
 (Select ts_sec, AVG((d3*256 + d2)*0.00390625) AS NavigationBasedSpeedKmPh
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEE8'
AND channel = 1
Group by ts_sec) As NavigationBasedSpeedKmPh On EngSpeedRpm.ts_sec =
NavigationBasedSpeedKmPh.ts_sec


   -- Using select statment to calculate wheel based speed (Km/h) by using its PGN
(FEF1)
LEFT JOIN
 (Select ts_sec, AVG((d2*256 + d1)*0.00390625) AS WheelBasedSpeed
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEF1'
AND channel = 1
Group by ts_sec) As WheelBasedSpeed On EngSpeedRpm.ts_sec = WheelBasedSpeed.ts_sec


   -- Using select statment to calculate pith angel (D ) by using its PGN (FEE8)
LEFT JOIN
 (Select ts_sec, AVG((d5*256 + d4)*0.0078125)-200 AS PitchD
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEE8'
AND channel = 1
Group by ts_sec) As PitchD On EngSpeedRpm.ts_sec = PitchD.ts_sec

--
 (Select ts_sec, AVG(d4*.25) AS Day
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEE6'
AND channel = 1
Group by ts_sec) As Day On EngSpeedRpm.ts_sec = Day.ts_sec


   -- Using select statment to determine planting hour (L/h) by using its PGN (FEE6)
LEFT JOIN
 (Select ts_sec, AVG(d2) AS Hour
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEE6'
AND channel = 1
Group by ts_sec) As Hour On EngSpeedRpm.ts_sec = Hour.ts_sec


 -- Using select statment to determine planting working time, minute (L/h) by using
its PGN (FEE6)
LEFT JOIN
 (Select ts_sec, AVG(d1) AS Minutes
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEE6'
```

```
AND channel = 1
Group by ts_sec) As Minutes On EngSpeedRpm.ts_sec = Minutes.ts_sec


   -- Using select statment to determine the elevation (m) by using its PGN (FEE8)
LEFT JOIN
(Select ts_sec, AVG((d7*256 + d6)*0.125)-2500 AS ElevationM
From ISU_Internal_CAN.dbo.can_raw_data_Seeding_2017
where ref_id = @ref_id
AND pgn = 'FEE8'
AND channel = 1
Group by ts_sec) As ElevationM On EngSpeedRpm.ts_sec = ElevationM.ts_sec


 -- Calculating Slip %
/*LEFT JOIN
 ((WheelBasedSpeed) - (NavigationBasedSpeedKmPh)/(WheelBasedSpeed)) AS SlipPercent
AND WheelBasedSpeed > NavigationBasedSpeedKmPh

Group by ts_sec) As SlipPercent On EngSpeedRpm.ts_sec = SlipPercent.ts_sec*/



   -- Using select statment to calculate planter motor speed (rpm) by using its PGN
(EFC5)
LEFT JOIN
(SELECT ts_sec, AVG((d2 + d3 * 256) * .25 -8000) AS MeterMotorSpdCmdRpm
FROM ISU_internal_can.dbo.can_raw_data_Seeding_2017
WHERE
ref_id = @ref_id  AND
pgn = 'EFC5' AND
sa = '91' AND
(channel = 3 OR channel = 4) AND
D0 = 244 AND
D1 = 44
Group by ts_sec) AS Meter on Meter.ts_sec = EngSpeedRpm.ts_sec


  -- Using where statment to specify the working condition for the unit
) WHERE (Meter.MeterMotorSpdCmdRpm > 50 AND WheelBasedSpeed.WheelBasedSpeed > 1 AND
WheelBasedSpeed.WheelBasedSpeed > NavigationBasedSpeedKmPh.NavigationBasedSpeedKmPh) -
-clipping results to only include data where planter is deployed into the soil

  order by EngSpeedRpm.ts_sec -- order results table by ts_sec
```

# APPENDIX C. [SAS CODE FOR TILLAGE]

```
proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

*For FuRte Response;
proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model FuRte = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;


*For S;
proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model s = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;
```

```
*For EFC;

proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model EFC = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;


*For FE;

proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model FE = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;
```

```
*For EnTqe;

proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model ENTqe = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;



*For EnPeld;

proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model EnPeld = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;
```

```
*For EnCoS;

proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model EnCoS = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;



*For SVD;

proc import out = tractor datafile =
"\\iastate.edu\cyfiles\abe_fsalim\Desktop\Tractor_Block.xlsx" DBMS =
excel;
      getnames = yes;
run;

ods pdf file = "Tractor_Block.pdf";
proc print; run;

proc glimmix data = tractor plots = all;
      class Wght TiPr Dep Pwr Block;
      model SVD = Block Wght|TiPr|Dep|Pwr;
      lsmeans Dep*Pwr / pdiff cl lines plot = meanplot(cl sliceby = Dep)
adjust = tukey;
      slice Dep*Pwr / sliceby = Dep cl lines;
      slice Dep*Pwr / sliceby = Pwr cl lines;
      lsmeans Tipr / pdiff cl lines;
      lsmeans Wght*TiPr*Dep*Pwr / cl;
      slice Wght*TiPr*Dep*Pwr / pdiff sliceby = Wght*TiPr*Dep cl plot =
meanplot(cl sliceby = Wght*TiPr*Dep);
run;
ods pdf close;
```

# APPENDIX D. [ABE410/510 SYLLABUS]

## Electronic Systems Integration for Agricultural Machinery and Production Systems
## SPRING 2018

**LECTURE:** Monday, 3:10 – 5:00 pm, Room 2306
**LAB:** Wednesday, 3:10 – 5:00 pm, Room TBD

**INSTRUCTORS:** Dr. Matthew Darr 2356 Elings Hall darr@iastate.edu
Phone: (515) 294-8545
Office hours by appointment.

Other key personnel will be assisting with this course due to their specialized expertise in specific areas. These include Mr. Jeff Askey (jcaskey@iastate.edu) and Dr. Bob McNaull (mcnaull@iastate.edu).

**UNIVERSITY COURSE DESCRIPTION:**

**A B E 410. Electronic Systems Integration for Agricultural Machinery and Production Systems.** (2-2) Cr. 3. S. System architecture and design of electronics used in agricultural machinery and production systems. Emphasis on information technology and systems integration for automated agriculture processes. Design of Controller Area Network (CAN BUS) communication systems and discussion of relevant standards (ISO 11783 and SAE J1939). Application of technologies for sensing, distributed control, and automation of agricultural machinery and electro-hydraulic systems will be emphasized.

**A B E 510. Electronic Systems Integration for Agricultural Machinery and Production Systems.** (2-2) Cr. 3. S. System architecture and design of electronics used in agricultural machinery and production systems. Emphasis on information technology and systems integration for automated agriculture processes. Design of Controller Area Network (CAN BUS) communication systems and discussion of relevant standards (ISO 11783 and SAE J1939). Application of technologies for sensing, distributed control, and automation of agricultural machinery and electro-hydraulic systems will be emphasized.

*Students will be expected to either complete an individual project or demonstrate the use of software simulation tools in problem solving to receive graduate credit.*

**STUDENT LEARNING OUTCOMES:**

Upon successfully completing this course, you should have gained or improved your:
1. Proficiency in CAN bus networks and interpretation of CAN bus data.
2. Production of analytical results and reports derived from electronic communication on agricultural vehicles.
3. Ability to integrate hardware and software components to achieve high performance, distributed sensor networking to support agricultural information technology.
4. Proficiency in the system design and technologies required by fully integrated electrical, mechanical, and fluid systems.
5. Understanding of ISO11783 and J1939 engineering standards and their role in open connectivity of ag machinery.
6. Proficiency in design and implementation of automated state machines for machine function control.

**COURSE ORGANIZATION:**

I. CAN Basics: Data frames, physical implementation, network management, and applicable standards
II. CAN Tools: Software tools for distributed control of off-road vehicle systems.
III. System Integration: Electro-hydraulic control of advanced off-road vehicle systems.

**REQUIRED TEXTS:**
1. Lecture Notes and Handouts Outlines: Available on Canvas.

**GRADING:**

| | |
|---|---|
| Midterm Exam I | 25% |
| Lab Practicum I | 10% |
| Lab Practicum II | 10% |
| Class Notebook | 30% |
| Final Exam | 25% |

**NOTE:** The instructor reserves the right to adjust the grading weights at any time.

**ASSIGNMENTS:**

This course will have an intensive homework and laboratory section that will challenge course members and provide hands on application of lecture material. Each homework and lab report should detail the procedure, goals and outcomes of the particular assignment as well as provide a clear explanation to any relevant questions. Any software code used must be provided in the report and should be appropriately commented. Students should be aware that considerable out of class time may be required to complete the lab project.

Late assignments will not be accepted. As a senior/graduate level course, this course in intended to prepare students for work experiences. As such, late work will simply not be accepted under any situation unless previously discussed with the course instructor. This policy covers both homework and lab assignments.

Requests for assignment re-grading must be made to the instructor in writing no later than 24 hours after the assignment was initially returned. The written request must contain an explanation of the re-grade question.

**LABORATORY POLICY:**

All students must successfully complete each lab assignment in its entirety. If a student must miss a scheduled lab, he/she must notify the instructor prior to the lab period and find an appropriate time to complete the lab exercises. Any incomplete lab assignments will result in a final grade assignment of Incomplete for the entire course.

**COURSE MEETING LOCATION:**

This course will meet in multiple rooms during the course of the semester including Elings 2306, Sukup 2207, Sukup 2209, Sukup 2211, and Sukup 1218. Students should monitor email and Canvas communication to confirm the room location. Elings 2306 is the default meeting location.

In the second half of the semester a separate course lab section at 3 – 5PM on Friday will be organized to meet room capacity in Sukup 2211. Students enrolled in the ABE 510 section are expected to attend the alternative Friday section.

**COURSE LESSONS LEARNED NOTEBOOK:**

All students must maintain a course notebook. This notebook will contain all reports and results from the course as well as an inventory of lessons learned topics. Specifically students are required to prepare a weekly technical journal which includes key lessons learned. This will include at a minimum techniques, tips, example solutions, and key new knowledge learned each week. This document will be ordered by week and will accumulate over the entire semester. The intent of this document is to provide a reference throughout the semester which will support lab activities in the project portion of the course.

This notebook will be submitted to be graded mid semester and at the end of the semester. The notebook will be graded based on completeness, organization, and quality of material. The notebook must contain a section on Course Notes, Lab and Homework Assignments, and the Lessons Learned Journal. Each section should be ordered chronologically to match the course plan.

The example grading rubric for the course notebook is:

| | Did Not Exist | Needs Improvement | Minimally Sufficient | Meets Expectations |
|---|---|---|---|---|
| Points | 0 | 1 | 3 | 5 |
| Course Notes: Completeness & Organization | | | | |
| Lab Reports: Completeness & Quality | | | | |
| Lessons Learned: Quality & Organization | | | | |
| Total Points | | | | |

**COURSE SCHEDULE:**

The following represents a preliminary course schedule. The instructor reserves the right to change the schedule based on class progress or other unforeseen conditions.

| Week | Date | Topic Area | Room | Friday Lab | Lecture Topic | Lab Topic |
|---|---|---|---|---|---|---|
| 1 | 1/8/2018 | CAN Basics | 2306 | - | Introduction, CAN Standards, CAN Physical Layer | |
| | 1/10/2018 | CAN Basics | 2306 | - | CAN Physical Layer Continued | |
| 2 | 1/15/2018 | CAN Basics | - | - | **Holiday - No Class** | |
| | 1/17/2018 | CAN Basics | 2306 | - | CAN Data Frame and Mobile Vehicle Standards | |
| 3 | 1/22/2018 | CAN Basics | 2306 | - | Network Management and Transport Protocol | |
| | 1/24/2018 | CAN Basics | 2306 | - | | Processing J1939 in Excel |
| 4 | 1/29/2018 | CAN Tools | 2306 | - | | Processing J1939 in Matlab |
| | 1/31/2018 | CAN Tools | 2306 | - | CANoe and Database File Introduction | |
| 5 | 2/5/2018 | CAN Tools | 2306 | - | CANoe Panels and Data Logs | |
| | 2/7/2018 | CAN Tools | 2306 | - | | Tractor Log File Dashboard |
| 6 | 2/12/2018 | CAN Tools | 2306 | - | | Live Tractor Dashboard |
| | 2/14/2018 | CAN Tools | 2306 | - | Programming in CANoe (CAPL and MBSD) | |
| 7 | 2/19/2018 | CAN Tools | 2207 & 2209 | - | | Address Claim and ISOBUS Beep |
| | 2/21/2018 | CAN Tools | 2207 & 2209 | - | | Address Claim and ISOBUS Beep |
| 8 | 2/26/2018 | CAN Tools | 2306 | - | MBSD and State Machines | |
| | 2/28/2018 | CAN Tools | 2207 & 2209 | - | | Joystick State Machine |
| 9 | 3/5/2018 | CAN Tools | 2207 & 2209 | - | | Joystick State Machine |
| | 3/7/2018 | CAN Tools | 2306 | - | **Midterm 1** | |
| 10 | 3/12/2018 | | | | **Spring Break - No Class** | |
| | 3/14/2018 | | | | | |
| 11 | 3/19/2018 | System Integration & Control | 2306 | - | Electronic Control of Hydraulic Circuits | |
| | 3/21/2018 | System Integration & Control | 2211 | Yes | | CAN Based Valve Control |
| 12 | 3/26/2018 | System Integration & Control | 2306 | - | Closed Loop Control | |
| | 3/28/2018 | System Integration & Control | 2211 | Yes | | Closed Loop Cylinder Control |
| 13 | 4/2/2018 | System Integration & Control | 2211 | Yes | | Closed Loop Cylinder Control |
| | 4/4/2018 | System Integration & Control | 2211 | Yes | | Closed Loop Motor Control |
| 14 | 4/9/2018 | System Integration & Control | 2211 | Yes | | Project Work |
| | 4/11/2018 | System Integration & Control | 2211 | Yes | | Project Work |
| 15 | 4/16/2018 | System Integration & Control | 2211 | Yes | | Project Work |
| | 4/18/2018 | System Integration & Control | 2211 | Yes | | Project Work |
| 16 | 4/23/2018 | System Integration & Control | 2211 | Yes | | Project Work |
| | 4/25/2018 | System Integration & Control | 2211 | Yes | | Project Work |
| Finals | 5/2/2018 | 12:00 - 2:00 PM | 2306 | - | **Final Exam** | |

**PREREQUISITES:**

Course prerequisites will be enforced according to University policy: [http://catalog.iastate.edu/informationaboutcourses/#prerequisitetext](http://catalog.iastate.edu/informationaboutcourses/#prerequisitetext). Students who are enrolled in this course but have not met the prerequisite requirements must drop the course. The instructor will not grade any coursework submitted by a student who has not met the course prerequisites and if the student does not drop this course, the student will earn an "F" grade for this course. Students who do not meet prerequisites but do have equivalent preparation may make a request for a prerequisite waiver.

**CLASSROOM ENVIRONMENT:**

**Safety Emphasis:** Students in ABE classes work with systems that, if misused, can be extremely hazardous. Therefore developing an attitude of safety is crucial to all engineering and technology professionals. Instructors may take an array of actions when students fail to complete required safety training (for example, by coming late to class and missing a safety briefing) or to adhere to procedures. These include but are not limited to (1) only allowing the student to observe the lab; (2) only allowing the student to observe the lab, and deducting points from the associated lab report; (3) suspending the student from all lab activities until the student has successfully completed the required safety portion of the lab (this may mean attending another lab section where the student can arrive on time); (4) dismissing students – and particularly repeat violators of safety policy – from the course.

**Academic Misconduct:** The class will follow Iowa State University's policy on academic dishonesty. Anyone suspected of academic dishonesty will be reported to the Dean of Students Office. Note that there ISU identifies several forms of academic dishonesty including: A student uses or attempts to use unauthorized information in the taking of an exam; submits as his or her own work, themes, reports, drawings, laboratory notes, computer programs, or other products prepared by another person; or knowingly assists another student in such acts or plagiarism.

Students found guilty of academic dishonesty in this class face suspension, conduct probation, or reprimand.

Please review these relevant policies:
http://www.dso.iastate.edu/ja/academic/misconduct.html.and
http://catalog.iastate.edu/academiclife/regulations/#academicdishonestytext.

**Disability Accommodation Policy**: Iowa State University is committed to assuring that all educational activities are free from discrimination and harassment based on disability status. All students requesting accommodations are required to meet with staff in Student Disability Resources (SDR) to establish eligibility. A Student Academic Accommodation Request (SAAR) form will be provided to eligible students. The provision of reasonable accommodations in this course will be arranged after timely delivery of the SAAR form to the instructor. Students are encouraged to deliver completed SAAR forms as early in the semester as possible. SDR, a unit in the Dean of Students Office, is located in room 1076, Student Services Building or online at www.dso.iastate.edu/dr/. Contact SDR by e-mail at disabilityresources@iastate.edu or by phone at 515-294-7220 for additional information.

**Dead Week**: For each Fall and Spring semester, the last full week of classes before final examinations is designated as Dead Week. The intent of Dead Week is to establish a one-week period of substantial and predictable study time for undergraduate students. During the Dead Week period, regular lectures are expected to continue, including the introduction of new content, as deemed appropriate by the instructor. The restrictions established by this Dead Week policy include:

- Due dates for mandatory graded submissions of any kind that fall within Dead Week must be listed on the syllabus provided at the start of the course.
- Mandatory final examinations may not be given during the Dead Week period except for laboratory courses or courses that meet weekly and for which there is no contact during the normal final examination week.

**Harassment and Discrimination:** Iowa State University strives to maintain our campus as a place of work and study for faculty, staff, and students that is free of all forms of prohibited discrimination and harassment based upon race, ethnicity, sex (including sexual assault), pregnancy, color, religion, national origin, physical or mental disability, age, marital status, sexual orientation, gender identity, genetic information, or status as a U.S. veteran.

Iowa State's Harassment and Discriminatory Harassment policy can be found here: http://www.policy.iastate.edu/policy/SDR#4.2.8.

In addition to not being discriminatory or harassing, it is my expectation that students treat their peers, any TAs, and the instructor, with respect and professionalism. Students engaging in any negative behaviors in this class, or in ABE facilities, are subject to appropriate disciplinary action by the course instructor, and will also have their cases referred to the Dean of Students Office.

Also, any student who observes such behavior should contact Dr. Mat Darr (darr@iastate.edu), and/or the Associate Chair of Teaching (Dr. Amy Kaleita, kaleita@iastate.edu, 515.294.5167), and/or Student Assistance at 515.294.1020 or email dso-sas@iastate.edu, and/or the Office of Equal Opportunity and Compliance at 515.294.7612.

Religious Accommodation: If an academic requirement of this class conflicts with your religious practices and/or observances, you may request reasonable accommodations. Your request must be in writing, and your instructor or supervisor will review the request. You or your instructor may also seek assistance from the Dean of Students Office or the Office of Equal Opportunity and Compliance.

Contact Information: If you are experiencing, or have experienced, a problem with any of the above issues, email academicissues@iastate.edu.

**ABE Code of Classroom Conduct**

All students have the right to learn without interference from others. Instructors, teaching assistants, and staff members have the authority to protect this right by creating and maintaining an environment that is conducive to learning. Toward this end, the department of Agricultural and Biosystems Engineering (ABE) has developed the following Code of Classroom Conduct.

Classroom misconduct is any behavior which disrupts or interferes with the learning experience. Students are required and expected to conduct themselves in a mature, considerate, and professional manner. Students should conduct and express themselves in a way that is respectful to all individuals. This includes respecting the rights of others to comment and participate fully in class. Classroom misconduct includes, but is not limited to, the following:

1. Engaging in behavior that disrupts or interferes with the learning experience. Behavior such as, but not limited to, talking in class while the instructor, teaching assistant or other students are speaking, using offensive language, creating distractions or disturbances, reading unrelated material, and moving about the classroom is, in many situations, considered disruptive behavior to the learning process.

2. Using cell phones or other electronic devices that disrupt the learning process or teaching environment is not allowed unless related to class activity. The use of personal laptop computers, phones, etc. may be acceptable in some classes; however they must be used only for note-taking or activities in direct support of the course objectives. Instructors and teaching assistants have the right to ask students to shut down any electronic device.

3. Entering the classroom late or leaving the classroom prior to the end of class is considered a disruption to the learning process and should be avoided unless exceptional circumstances arise or prior notice has been given.

Harassment of anyone will not be tolerated in any form. Harassment includes offensive gestures or verbal comments related to race, ethnicity, religion, disability, physical appearance, gender, age, or sexual orientation, deliberate intimidation, stalking, following, harassing photography or recording, sustained disruption of classes or other events, inappropriate physical contact, circulation of written or graphic material that denigrates or shows hostility or aversion, and unwelcome attention.

Iowa State University strives to maintain our campus as a place of work and study for faculty, staff, and students that is free of all forms of prohibited discrimination and harassment based upon race, ethnicity, sex (including sexual assault), pregnancy, color, religion, national origin, physical or mental disability, age, marital status, sexual orientation, gender identity, genetic information, or status as a U.S. veteran. Any student who has concerns about such behavior should contact the course instructor, the ABE Associate Chair for Teaching (Dr. Amy Kaleita, 515.294.5167, kaleita@iastate.edu), Student Assistance (515.294.1020, dso-sas@iastate.edu, http://www.studentassistance.dso.iastate.edu,), or the Office of Equal Opportunity (515.294.7612, eooffice@iastate.edu, http://www.eoc.iastate.edu/).

Adopted by the ABE Faculty October 21, 2016

# APPENDIX E. [COURSE SURVEYS]

**Pre-Assessment:**

1- What do you know about Controller Area Network (CAN)? What is the definition of CAN messages and signals?

2- What do you know about CAN physical layer that connects the multiple components?

3- Have you worked in teams before?
If yes, how have you intentionally applied your knowledge and skills to your team interactions?

4- Do you have any knowledge about J1939 or ISO 11783 standard?
If so, what is it? Make a list or write a short paragraph about this knowledge.

5- Are you confident in using CAN in Ag applications? Why or why not?

6- Do you have any background in using Excel, Matlab, and programing?
If yes, please describe.

7- Do you have any knowledge about controlling and monitoring machines?
If yes, please describe what this knowledge is.

**Weekly lab notebook:**

- Explain at least 3 main ideas from the week.
- Provide the most important results.
- What enhanced your learning this week? Why was this helpful?
- What is most unclear to you from this week?

**Course survey:**

1. On a scale of 1 to 5, how strongly do you agree or disagree with the following statement? Course structures and experiences in ABE410 are helping me meet the learning outcome: "Ability to interpret CAN bus data”

   (strongly agree) 1 2 3 4 5 (strongly disagree)
   Please explain why you chose that rating.

2. On a scale of 1 to 5, how strongly do you agree or disagree with the following statement? Course structures and experiences in ABE410 are helping me meet the learning outcome: "Ability to integrate hardware and software components to support agricultural information technology”

   (strongly agree) 1 2 3 4 5 (strongly disagree)
   Please explain why you chose that rating.

3. On a scale of 1 to 5, how strongly do you agree or disagree with the following statement? The overall environment in ABE410 **Lecture** has been helpful for my learning.

   (strongly agree) 1 2 3 4 5 (strongly disagree)
   Please explain why you chose that rating.

4. On a scale of 1 to 5, how strongly do you agree or disagree with the following statement? The overall environment in ABE410 Lab has been helpful for my learning.

   (strongly agree) 1 2 3 4 5 (strongly disagree)
   Please explain why you chose that rating.

5. What course structures or experiences have you enjoyed about ABE410 **Lecture** thus far? Please be specific and explain how each has been helpful for your learning.

6. What course structures or experiences have you enjoyed about ABE410 Lab thus far? Please be specific and explain how each has been helpful for your learning.

7. What can be done differently in the ABE410 **Lecture** to make it a better learning environment for you? Please be specific and include why the change(s) would help you learn.

8. What can be done differently in the ABE410 Lab to make it a better learning environment for you? Please be specific and include why the change(s) would help you learn.

9. Has there been anything that interfered with you meeting the learning outcomes? Please be specific and include the reason it interfered.

10. If there has been anything that has hindered or made your learning difficult, what steps can be taken to change these circumstances?

11. In this class, what are ***you*** doing that helped support your learning?

12. In this class, what are ***you*** doing that needs to be changed to help support your learning?

13. How many hours per week do you spend on this course (outside of the normal class periods)?

    (1-2) (2-3) (3-4) (4-5) (5-6) (6-7) (7-8 ) (more than 8 hours)

**For the following statements, use the scale to indicate how well you agree with each statement.**

14. The instructor consistently and effectively explained concepts and clarified areas of confusion.

(strongly agree) 1 2 3 4 5 (strongly disagree)

Please explain why you chose that rating.

15. The instructor used teaching methods and classroom activities that enhanced my achievement of the expected student learning outcomes.

(strongly agree) 1 2 3 4 5 (strongly disagree)

Please explain why you chose that rating.

16. The instructor regularly illustrated the relevance of course content to practical engineering or technology situations, through any one of a combination of the following: case studies, news stories, humor, personal experiences, or other appropriate methods.

(strongly agree) 1 2 3 4 5 (strongly disagree)

Please explain why you chose that rating.

17. The instructor encouraged class participation by asking questions and/or holding students accountable for meeting the learning outcomes.

(strongly agree) 1 2 3 4 5 (strongly disagree)

Please explain why you chose that rating.

18. Assignments were related to the expected student learning outcomes.

(strongly agree) 1 2 3 4 5 (strongly disagree)

Please explain why you chose that rating.

19. The instructor's (and/or grader's) feedback (oral, written, electronic) was helpful for enhancing my learning.

(strongly agree) 1 2 3 4 5 (strongly disagree)

Please explain why you chose that rating.

20. The text, lecture notes, videos, and/or other supplementary resources used in this course were effective for helping me meet the expected student learning outcomes.

(strongly agree) 1 2 3 4 5 (strongly disagree)

21. The content of this course has helped me understand the basic concepts in the course syllabus and will support my future career.

(strongly agree) 1 2 3 4 5 (strongly disagree)

22. The instructor treated students with respect.

(strongly agree) 1 2 3 4 5 (strongly disagree)

23. The instructor used time wisely.

(strongly agree) 1 2 3 4 5 (strongly disagree)

24. The instructor attended to course interaction.

(strongly agree) 1 2 3 4 5 (strongly disagree)

25. The instructor demonstrated leadership ability.

(strongly agree) 1 2 3 4 5 (strongly disagree)

26. The instructor maintained discipline and control.

(strongly agree) 1 2 3 4 5 (strongly disagree)

**Post- Assessments:**

1- What do you know about Controller Area Network (CAN)? What is the definition of CAN messages and signals?

2- What do you know about CAN physical layer that connects the multiple components?

3- Have you worked in teams before?
If yes, how have you intentionally applied your knowledge and skills to your team interactions?

4- Do you have any knowledge about J1939 or ISO 11783 standard?
If so, what is it? Make a list or write a short paragraph about this knowledge.

5- Are you confident in using CAN in Ag applications? Why or why not?

6- Do you have any background in using Excel, Matlab, and programing?
If yes, please describe.

7- Do you have any knowledge about controlling and monitoring machines?
If yes, please describe what this knowledge is.